Technical Report

CONTINUOUS-SIMULATION COMPONENTS FOR PESTICIDE ENVIRONMENTAL ASSESSMENT WITH VFSMOD: 1. VFS SOIL WATER DYNAMICS BETWEEN RUNOFF EVENTS

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Executive Summary

VFSMOD (Muñoz-Carpena et al., 1999; 2004) is a numerical, storm-based design model. During the rainfall-runoff event it calculates the dynamic hydrological and transport processes occurring in the vegetative filter strip (VFS). For this it uses initial conditions (soil water, vegetation) and boundary conditions (rainfall, inflow runoff from the field) and calculates outflow hydrographs and pollutographs (sediment, pesticides, reactive solutes) for the storm, as well as the water and mass balances at the end of the storm. The model has been coupled into current long-term higher-tier pesticide environmental assessment framework (US EPA and EU FOCUS SWAN shell) where the field management and pesticide runoff at the end of the field is calculated by the model PRZM and VFSMOD routes it from the edge of field through a VFS of desired characteristics to estimate potential load reductions before entering the aquatic environment. Long-term simulations require realistic initial conditions at the beginning of each runoff event in the time series (initial soil water, pesticide residue and vegetation status).

Herein, we present the procedure adopted to calculate the VFS topsoil water content dynamics between runoff events based on FAO-56 (FAO, 1998) adjusted evapotranspiration and soil water mass balance calculations. This allows for estimation of the initial soil water content (OI) at the beginning of each runoff event in the long-term environmental assessment time series. A user-friendly computer program (THETAFAO) is developed and documented for inclusion in the FOCUS–SW framework as a preprocessor of existing meteorological files (MET) that adds VFS soil daily water estimations (OI) in the continuous simulation of pesticide environmental assessments with VFSMOD.

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Calculation of top-soil water between storm runoff events for the continuous simulation of VFS effectiveness with VFSMOD

Description

VFSMOD (Muñoz-Carpena et al., 1999; 2004) is a numerical, storm-based design model. During the rainfall-runoff event it calculates the dynamic hydrological and transport processes occurring in the vegetative filter strip (VFS). For this it uses initial conditions (soil water, vegetation) and boundary conditions (rainfall, inflow runoff from the field) and calculates outflow hydrographs and pollutographs (sediment, pesticides, other) for the storm, as well as the water and mass balance at the end of the storm. To move the model into, long-term continuous simulation mode for pesticide regulatory assessments, the model has been coupled into the current environmental assessment framework (US EPA and EU FOCUS) where the field management and pesticide runoff at the end of the field is calculated by the model PRZM and VFSMOD routes it from the field through a VFS of desired characteristics to estimate potential load reductions before entering the aquatic environment. Long-term simulations require realistic initial conditions (initial soil water, pesticide residue, vegetation status) in the VFS at the beginning of the calculations for each runoff event in the time series. Herein, the procedure adopted to estimate initial VFS soil water content at the beginning of each runoff event is presented.

The soil water content can be determined from the other soil water (mass) balance components. The method presented here is based on FAO-56 detailed estimation of adjusted evapotranspiration under soil water stress limiting conditions (FAO, 1998). The method consists of assessing the incoming and outgoing water flux into the vegetation root zone over a daily time increment (Figure 1).

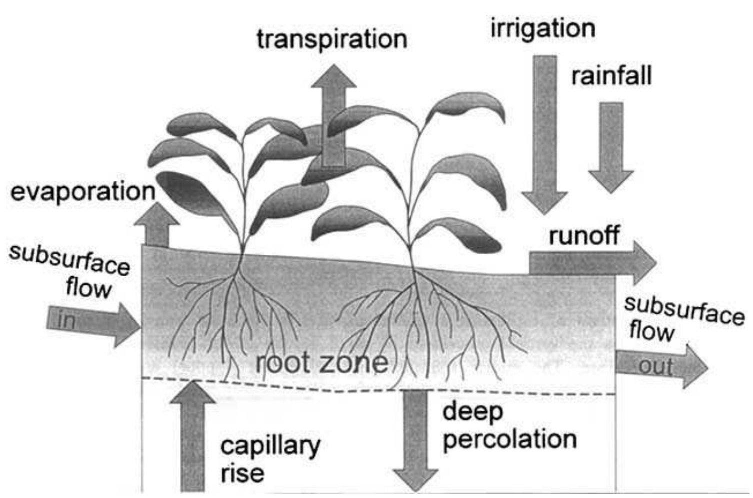

Figure 1. Soil water balance (from FAO, 1998)

Irrigation (*I*) and rainfall (*P*) add water to the root zone. Part of *I* and *P* might be lost by surface runoff (RO) and by deep percolation (*DP*) that will eventually recharge the water table. Water might also be transported upward by capillary rise (*CR*) from a shallow water table towards the root zone or even transferred horizontally by subsurface flow in (SF_{in}) or out of (SF_{out}) the root zone. Soil evaporation and crop transpiration, evapotranspiration (*ET*), deplete water from the root zone. If all fluxes other than the soil water content variation (θ) can be assessed, θ can be deduced from the change in actual ET over the time period,

$$\Delta\theta = P + I - ET - RO - DP + CR \pm \Delta SF \qquad (1)$$

In many situations, however, except under conditions with large slopes, SF_{in} and SF_{out} are minor and can be ignored. In a typical VFS (no irrigation) and for periods between runoff events (RO=0) when not shallow water table is present Eq. 1 can be simplified to,

$$\Delta\theta = P - ET - DP \qquad (2)$$

FAO-56 (FAO, 1998) allows for a detailed estimation of the actual ET based on environmental factors including atmospheric and soil characteristics. The method relies on the adjustment of potential ET rates (ET_o) to match the local conditions during time, i.e. limitations to ET imposed by the vegetation, weather or soil water. For this it requires daily rainfall and ET_o, soil characteristics and vegetation characteristics that are readily available in the environmental assessment framework (PRZM inputs/outputs) or FAO recommendations. Some fluxes such as subsurface flow, deep percolation and capillary rise from a water table are difficult to assess and short time periods cannot be considered. The full soil water balance method can usually only give ET estimates over long-time periods of the order of week-long or ten-day periods. However, for conditions between runoff events and deep water table the method has been proven simple and reliable for the prediction of the daily soil surface water content when compared to field probe measurements (0-30 cm) (Pers. comm, M. Quemada, Univ. Politécnica Madrid). Although the accuracy of the method to predict daily soil water variation declines for deeper soil water estimates, root zone estimates are sufficient for the infiltration calculations in VFSMOD.

The assumptions, inputs and the calculation procedure are described below along with a computer program developed for these calculations and an application example (see Appendices).

Input requirements

The list of inputs required for the calculation and their source is summarized below.

a) *Soil physical characteristics* (.IN input file)
- θ_i (-, frac): soil water initial content. This is the same as OI in VFSMOD input file (.ISO).
- θ_{FC} (-, frac): soil water field capacity. This can be taken from EU FOCUS R1-R4 scenario parameters used by the PRZM model. FAO recommendations based on soil type are included in Table 1 (FAO, 1998) (see Appendices D-E for EU-FOCUS soils).
- θ_{WP} (-, frac): soil water wilting point. This can be taken from EU FOCUS R1-R4 scenario parameters used by the PRZM model. FAO recommendations based on soil type are included in Table 1 (FAO, 1998) (see Appendices D-E for EU-FOCUS soils).

Table 1. Typical soil water characteristics for different soil types (from FAO-56)

Soil Texture (USDA)	θ_{FC} (m^3m^{-3})	θ_{WP} (m^3m^{-3})	(θ_{FC} - θ_{WP}) (m^3m^{-3})
Sand	0.07–0.17	0.02–0.07	0.05–0.11
Loamy sand	0.11–0.19	0.03–0.10	0.06–0.12
Sandy loam	0.18–0.28	0.06–0.16	0.11–0.15
Loam	0.20–0.30	0.07–0.17	0.13–0.18
Silt loam	0.22–0.36	0.09–0.21	0.13–0.19
Silt	0.28–0.36	0.12–0.22	0.16–0.20
Silt clay loam	0.30–0.37	0.17–0.24	0.13–0.18
Silty clay	0.30–0.42	0.17–0.29	0.13–0.19
Clay	0.32–0.40	0.20–0.24	0.12–0.20

b) *Soil evaporation characteristics* (.IN input file)
- p (-): the fraction of the total soil available water that a crop can extract from the root zone without suffering water stress. For Bermuda grass p=0.6 is taken from the range suggested by FAO (1998) (see Appendix C).

c) *Vegetation characteristics* (.IN input file)
- $K_{c,mid}$ (-): mid-season crop coefficient (maximum). For well-established dense, full-cover grass vegetation the $K_{c,mid}$ is equivalent to the values for the initial and end stages of the season ($K_{c,ini}$, $K_{c,end}$). FAO-56 (FAO, 2008) recommends $K_{c,mid}$ =0.95 (hot season turf grass), $K_{c,mid}$ =0.85 (cool season turf grass) and $K_{c,mid}$ =0.85-1.05 (grazing pasture). For simplicity, a value of $K_{c,mid}$ =1 (FAO-56 reference crop) for VFS grass is proposed here for weather adjustment (as described below), subject to further investigation. Notice that from *thetafao* v0.6 (Dec. 2019) the program allows for the user to provide a variable $K_{c,mid}$ value for plants other that grass (see details for flag *iFM* in Appendix A, sect 2.2.1).
- Z_r (m): maximum root zone depth. For Bermuda grass Z_r=1 m is taken from the range suggested by FAO-56 (FAO, 1998) (see Appendix C).
- h (m): vegetation height. H is the effective (rigid) vegetation height typically maintained by mowing the grass at a recommended height. This is equivalent to H(/100) factor in VFSMOD.

d) *Weather boundary conditions* (.MET input file)

Daily weather, i.e. ET_o (reference or potential, mm/d), rain (P, mm/d), minimum air relative humidity (RH_{min} , %) (or minimum and maximum air temperature, T_{min} and T_{max}, °C), daily average wind speed at 2 m (u_2 , m/s). These are obtained daily from FOCUS/PRZM field simulation files (ET_o, P), or other sources in other applications.

Root zone soil water content calculation procedure

The method is based on the adjustment of the daily reference or potential evapotranspiration (obtained from PRZM) based on environmental stresses caused by soil water shortage, fertility, disease, grazing or insect damage or due to low plant density,

$$ET_c = ET_o K_c$$
$$ET_a = ET_o (K_c K_s) \quad (3)$$

where ET_c is the crop evapotranspitation (mm/d), ET_o is the reference or potential evapotranspiration (mm/d), ET_a is the actual (adjusted) evapotranspiration (mm/d), and K_c and K_s are the crop and soil (water stress) coefficients. The crop coefficient K_c (0-1) is adjusted daily based of the mid-season maximum value and weather conditions as,

$$K_c = K_{c,mid} + [0.04(u_2 - 2) - 0.004(RH_{\min} - 45)]\left(\frac{h}{3}\right)^{0.3} \tag{4}$$

As described in FAO-56 (FAO, 1998), water content in the root zone can also be expressed by root zone depletion (mm) at the end of the day, $D_{r,i}$, i.e., water shortage relative to field capacity. At field capacity, the root zone depletion is zero ($D_{r,i} = 0$). When soil water is extracted by evapotranspiration, the depletion increases and stress will be induced when $D_{r,i}$ becomes equal to *RAW* (readily available water, mm*)*. After the root zone depletion exceeds *RAW* (the water content drops below the threshold θ_t), the root zone depletion is high enough to limit evapotranspiration to less than potential values and the crop evapotranspiration begins to decrease in proportion to the amount of water remaining in the root zone until it reaches a minimum at the soil wilting point, $D_{r,i} = TAW$ (Fig. 2).

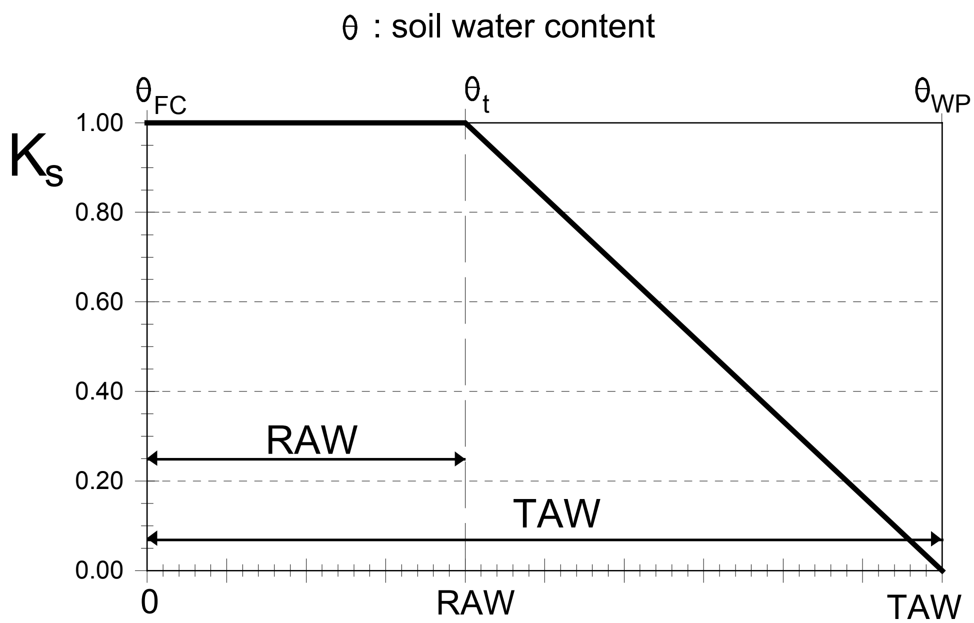

Figure 2. Water stress coefficient (from FAO, 1998)

For $D_{r,i} > RAW$, K_s (0-1) is calculated as,

$$K_s = \begin{cases} \dfrac{TAW - D_{r,i}}{TAW - RAW} = \dfrac{TAW - D_{r,i}}{(1-p)TAW} & D_{r,i} > RAW \\ 1 & D_{r,i} \le RAW \end{cases} \tag{5}$$

where *TAW* is the total available soil water in the root zone [mm], and *p* is described below.

Soil water availability refers to the capacity of a soil to retain water available to plants. After a heavy rainfall or irrigation, the soil will drain until field capacity is reached. TAW is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and the rooting depth. As the water content above field capacity cannot be held against the forces of gravity and will drain. The water content below the wilting point cannot be extracted by plant roots so the total available water in the root zone (*TAW*) is the difference between the water content at field capacity and wilting point,

$$TAW = 1000\ Z_r\ (\theta_{FC} - \theta_{WP}) \tag{6}$$

where *TAW* the total available soil water in the root zone [mm], θ_{FC} the water content at field capacity [m^3m^{-3}], θ_{WP} the water content at wilting point [m^3m^{-3}], Z_r the rooting depth [m]. Typical ranges for field capacity and wilting point are listed in Table 1 for various soil texture classes. Ranges of the maximum effective rooting depth for various crops are given in FAO-56 (Allen et al., 1998).

The readily available water (*RAW*) is calculated as the fraction of *TAW* the vegetation can extract before suffering water stress. This is caused by the water retention by the soil that makes more difficult the extraction of water at higher potentials (drier soil). This is calculated as,

$$RAW = TAW\ .\ p \tag{7}$$

where *RAW* the readily available soil water in the root zone [mm], *p* [0 - 1] is the fraction of TAW that can be depleted from the root zone before water stress (reduction in ET) occurs. For daily calculations *p* is adjusted daily from the average value based on the crop ET ($ET_c = K_c\ ET_o$). Typical values of average *p* (p_{avg}) for different plants are listed in FAO-56 (1998) but values recommended for dense grass are p_{avg}=0.6. The factor *p* normally varies from 0.30 for shallow rooted plants at high rates of ET_c (> 8 mm d^{-1}) to 0.70 for deep-rooted plants at low rates of ET_c (< 3 mm d^{-1}). The daily adjustment is made by,

$$p = p_{avg} + 0.04\ (5 - ET_c) = p_{avg} + 0.04\ (5 - K_c\ ET_o) \quad \text{with } 0.1 \le p \le 0.8 \tag{8}$$

To initiate (*i*=1) the water balance for the root zone, the initial depletion $D_{r,i-1}$ should be estimated. The initial depletion can be derived from measured soil water content by:

$$D_{r,0} = D_{r,i-1} = 1000(\theta_{FC} - \theta_{i-1})Z_r \tag{9}$$

where θ_{i-1} is the average initial soil water content for the root zone. If the initial soil water content is not known and the calculation is started following a heavy rain or irrigation, the user can assume that the root zone is near field capacity, i.e., $D_{r,0} \approx 0$. During the daily time steps soil evaporation, crop transpiration and percolation losses remove water from the root zone and increase the initial depletion unless rainfall is received during the day. Thus, the depletion at the end of day *i* is expressed in terms of the soil water balance (assuming no capillary rise from a shallow water table and no irrigation for the period with no runoff) as,

$$D_{r,i} = D_{r,i-1} - P_i + ET_{c,i} + DP_i \tag{10}$$

where $D_{r,i-1}$ is water content in the root zone at the beginning of the day [mm], P_i precipitation on day *i* [mm], $ET_{c,i}$ is the crop evapotranspiration on day *i* [mm], DP_i [mm] is the water loss out of the root zone by deep percolation on day *i* [mm]. All terms in Eq. (10) are known after the first time step except for the deep percolation (DP_i). This can be estimated as the amount of water in the soil exceeding the field capacity after a rainfall event,

$$DP_i = P_i - ET_{c,i} - D_{r,i-1} \ge 0 \tag{11}$$

When the soil water content in the root zone is below field capacity (i.e., $D_{r,i} > 0$), the soil will not drain and DP_i=0. where DP_i = 0 if eq. (11) yields a negative value.

Finally, the soil water content at the end of day i (θ_i, m^3/m^3) can be estimated as the remaining soil water from field capacity minus the root zone depletion,

$$\theta_i = (1000\ Z_r\ \theta_{FC} - D_{r,i})/(1000\ Z_r) \qquad (12)$$

Order of calculations

The following orders should be followed in the calculations (Appendix C) 1) RH_{min} (%) (eq. 13); 2) K_c (eq. 4); 3) ET_c (mm/h) (eq. 3); 4) p (eq. 8); 5) RAW (mm) (eq. 7); 6) $D_{r,i-1}$ (mm) (for i=1, eq. 9); 7) DP_i (mm) (eq. 11); 8) $D_{r,i}$ (mm) (eq. 10); 9) K_s (eq. 5); 10) ET_a(mm/d) (eq. 3); and 11) θ_i (m^3/m^3) (eq. 12).

Missing relative humidity meteorological data

FOCUS meteorological files (.MET) files contain the basic weather information (Table 2) needed for the topsoil water calculation except for the relative humidity (RH_{min}) value needed in eq. (4).

Table 2. Description of EU-FOCUS PRZM MET files (source: http://focus.jrc.ec.europa.eu/sw/index.html)

PARAMETER AND DESCRIPTION	VALUE, SOURCE AND COMMENTS
Meteorological files MMDDYY: meteorological month/day/year PRECIP: precipitation (cm/day) PEVP: pan evaporation (cm/day) TEMP: temperature (Celsius) WIND: wind speed (cm/sec) SOLRAD: solar radiation (Langley)	The PRZM in FOCUS shell includes 4 non-irrigated location specific meteorological files (e.g. R1NOIRR.MET for scenario R1) and 32 irrigated location and crop specific meteorological files (e.g. R1MAIZE.MET for maize in scenario R1). All files cover the period 1 Jan 1975 to 32 Dec 1994 and are in the format required by PRZM.

It is possible to approximate the daily minimum relative humidity value if the daily maximum (T_{max}) and minimum (T_{min}) or dew (T_d) temperatures are known for each of the FOCUS EU scenarios based on nearby weather stations. Using the Magnus-Tetens equation (revision by Alduchov and Eskridge, 1996) the approximation is,

$$RH_{min} \approx 100\frac{e_a}{e_s(T_{max})}$$
$$e_a \approx e_a(T_d) \approx e_a(T_{min}) = 0.61121e^{\frac{17.625T_{min}}{T_{min}+243.04}} \qquad (13)$$
$$e_s(T_{max}) = 0.61121e^{\frac{17.625T_{max}}{T_{max}+243.04}}$$

For daily values and irrigated or humid/subhumid crop areas, it is common to assume that the dew temperature is close to the minimum temperature. However, for arid areas this assumption needs to be evaluated locally.

Wind speed height conversion

For cases when wind velocity is collected at heights other that 2 m above the ground (for example 10 m is common), the wind velocity must be converted the standard 2 m (u_2) required by eq. (4). Several equations that account for the boundary surface layer have been proposed, typically describing a logarithmic wind profile with height above ground. FAO-56 recommends a simplified equation,

$$u_2 = u_z \frac{4.87}{\ln(67.8z - 5.42)} \qquad (14)$$

where u_z is the average wind speed (m/s) measure at height z (m) above the ground.

Previous testing of the soil water calculation

McCready and Dukes (2011) tested the performance of the water balance equations (eq. 2 and eq. 10) to estimate root zone soil water content in a turf grass experiment (eq. 12). Weather variables, ET_c and θ_i in the root zone were measured independently. The experiment consisted of well-established St. Augustine grass (*Stenotaphrum secundatum*) growing on a sandy Arredondo soil with minimum precipitation frequency (irrigation) of 1 day per week to match local ET_c values + local precipitation received during the experiment. The active root zone was measured at 30 cm. Figure 3 shows the comparison between measured soil water content at the end of the day (using TDR) and the predicted soil water content values with the water balance equation (Eq. 12) at the end of each day.

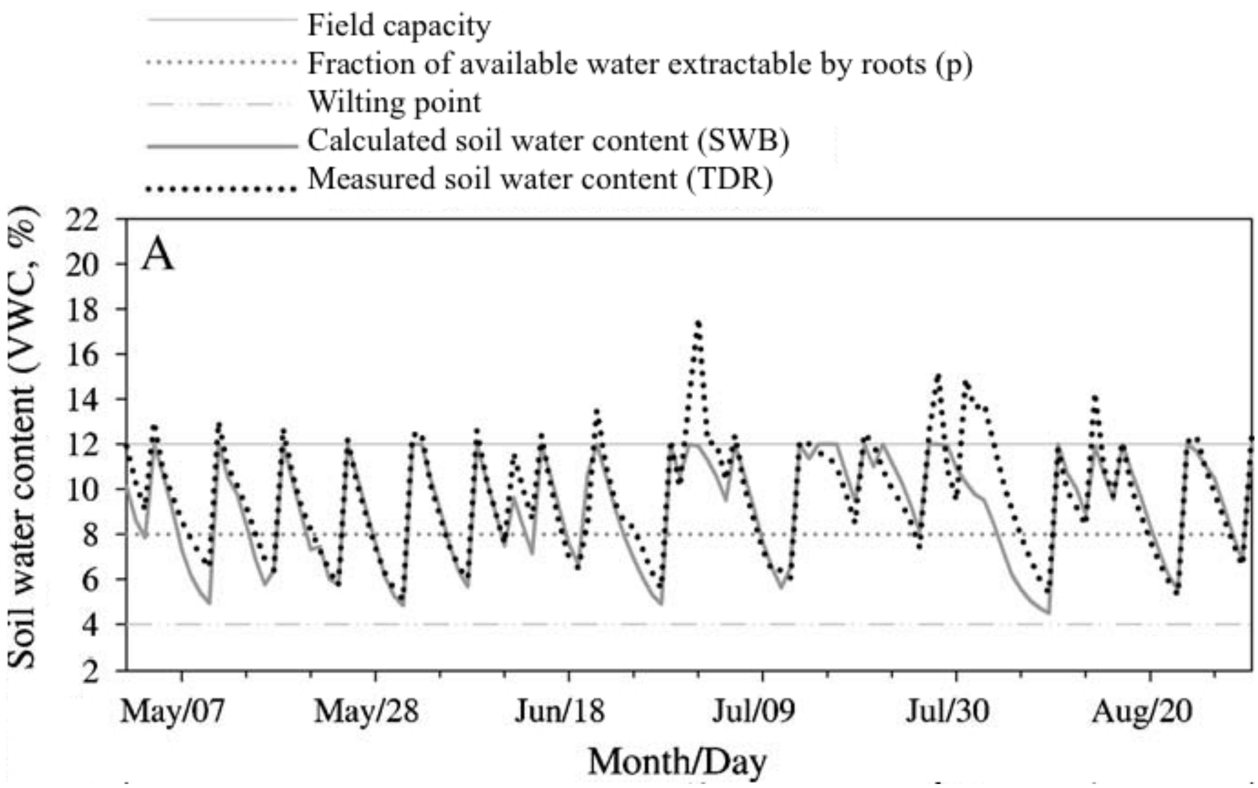

Figure 3. Example of soil volumetric content calculated daily using the soil water balance (SWB, Eq. 12) on well-established warm season grass with 30 cm root depth (adapted from Fig. 2 on McCready and Dukes, 2011).

The equation predicted well (RMSE=1.4% volumetric moisture content units, Nash-Sutcliffe model efficiency, NSE=0.75). The largest differences were observed for early infiltration periods where the soil moisture was maintained above field capacity by wet conditions resulting from larger rainfall events. As soon as the soil water content fell to the field capacity, the calculated values followed the TDR trend well.

Example application

Example results for the proposed calculations are presented for a VFS consisting of a dense stand of Bermuda grass under EU FOCUS R1 scenario conditions (R1NOIRR.MET) in a loamy soil. The grass is maintained at 35 cm through regular mowing to maintain a thick stand of vegetation (full soil cover, f_c=1). Relevant inputs are presented in Table 3 and the results of the calculation in Fig. 4. Details of the computer program and input and output files are provided in the Appendices F and G.

Table 3. Soil and vegetation factors for the example application

Factor (units)	Symbol	Value
Soil type (USDA) [a]	*soiltype*	-1 (user)
Initial water (mm) [a]	θ_i	25.0
Field capacity (mm) [a]	θ_{FC}	27.5
Wilting point (mm) [a]	θ_{WP}	17.08
Total available water (mm) [b]	*TAW*	10.42
Fraction of easily extractable water	p	0.6
Root zone depth (m)	Z_r	1
Crop coefficient (max)	$K_{cb,mid}$	1.00
Vegetation height (m)	h	0.35

[a] If soiltype =1-9, predefined values from Table 1 are used. [b] TAW= 1000(θ_{CC} – θ_{WP}) Z_r

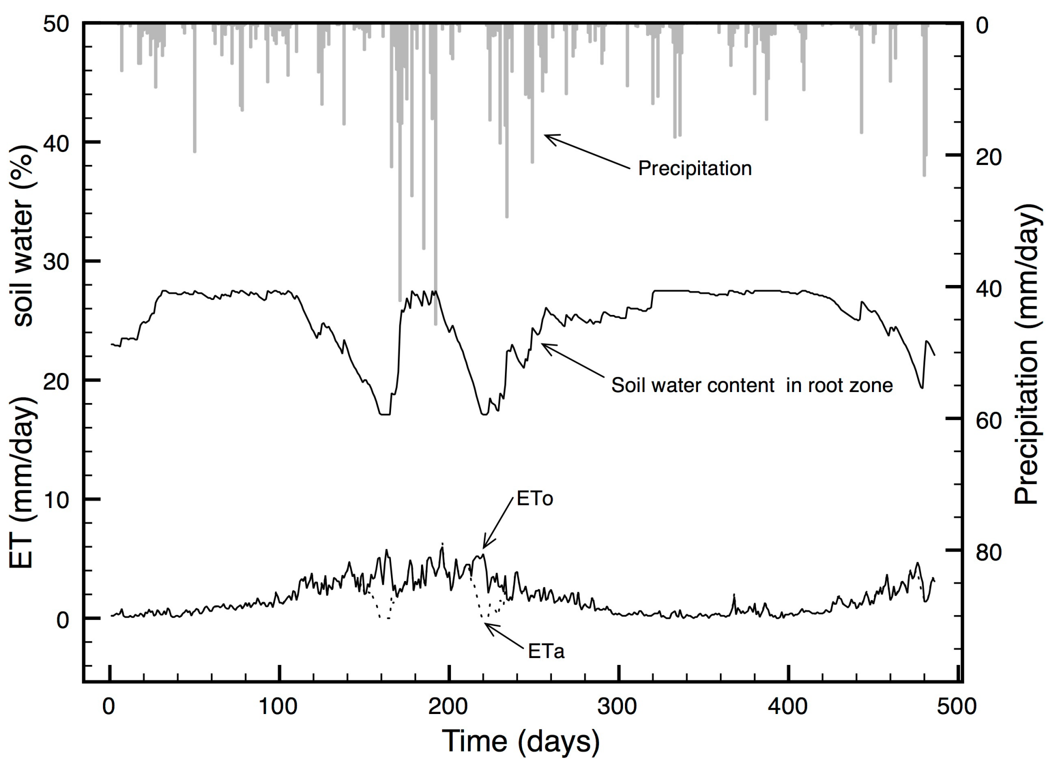

Figure 4. Calculation of soil water content variation for the vegetative filter strip for the example case

References

Alduchov, O. A., and R. E. Eskridge, 1996: Improved Magnus form approximation of saturation vapor pressure. J. Appl. Meteor., 35, 601–609.

Allen, R. L.S. Pereira, M. Smith, D. Raes and J.L. Wright. 2005. FAO-56 dual crop coefficient method for estimating evapotranspiration from soil and application extensions. *J. of Irrigation and Drainage Engineering* 131(1):2-13.

Buck, A.L. 1981. New equations for computing vaport pressure and enhancement factor. *J. of Appl. Meteor*. 20:1527-1532

McCready, M.S. and M.D. Dukes. 2011. Landscape irrigation scheduling efficiency and adequacy by various control technologies. *Ag. Water Manag*. 98:697-704. doi: 10.1016/j.agwat.2010.11.007

Muñoz-Carpena, R., J.E. Parsons, and J.W. Gilliam. 1999. Modeling hydrology and sediment transport in vegetative filter strips. *Journal of Hydrology* 214(1-4):111-129.

Muñoz-Carpena, R. and J.E. Parsons. 2004. A Design Procedure for Vegetative Filter Strips Using VFSMOD-W. *Trans. of ASAE* 47(5):1933-1941.

EU FOCUS. 2010. Overview of FOCUS Surface Water. http://focus.jrc.ec.europa.eu/sw/index.html

Food and Agriculture Organization (FAO). 1998. FAO-56 Crop Evapotranspiration: Guidelines for Computing Crop Requirements. http:// www.fao.org/docrep/X0490E/X0490E00.htm, accessed November 10, 2004.

LIST OF APPENDICES

APPENDIX A - Description of Program THETAFAO

THETAFAO is a FORTRAN program to calculate soil water content in the VFS between runoff events. This is a necessary step for continuous simulation of the PRZM/VFSMOD EU FOCUS shell. The result of the calculation will produce the daily soil water content from which the initial water content of the soil (OI) is selected for the next VFSMOD run in the time series. It follows FAO-56 calculations for a single crop coefficient with uniform soil cover (Allen et al., 1998).

2.1 Installing and running THETAFAO

THETAFAO.EXE can be installed in any directory and must have two subdirectories under it (INPUTS and OUTPUT). When running THETAFAO from the command line (DOS and UNIX versions) the name of the input file set to process is selected at the command line. To find a brief description of the program type the program name in the DOS or UNIX command line and press <return>,

```
C:\THETAFAO\> thetafao    <return>

Name:    thetafao
         (VFSMOD-FOCUS:calculate soil water between events)
Usage:   thetafao filename (max 8 characters, no ext.)
Version: 0.7 for Windows -Nov 2022
Authors: R.Munoz-Carpena (UFL), carpena@ufl.edu
```

To process the EU-FOCUS .MET from the command line the program is followed by the name of the MET file without the .MET extension. As an example one would run:

```
C:\THETAFAO\> thetafao R1NOIRR   <return>
```

In this example, the input files R1NOIRR.IN and R1NOIRR.MET must be present in the INPUTS subdirectory, i.e. **BOTH** files must have the same name and extensions .IN and .MET (see file contents in sect. 2.2.1). After you execute the command you should see a screen as follows:

```
THETAFAO v0.7, 11/2022
R.Munoz-Carpena (UFL), carpena@ufl.edu

 ...Opening files...
inputs/R1NOIRR.in
inputs/R1NOIRR.met
output/R1NOIRR.out
output/R1NOIRR.met

 ...FINISHED!...
```

During the run two output files are created in the OUTPUT subdirectory that summarize the calculations performed (R1NOIRR.OUT and R1NOIRR.MET). The content of the .OUT is produced in verbose mode and is self-explanatory (see below).

The .MET file in the OUTPUT directory is the same as that in the INPUTS directory except a new column is added at the end with the daily soil water content, θ_i (m^3/m^3), where Z_r (m) is the thickness of the root zone where the moisture is calculated. The value θ_i for the day when PRZM predicts surface runoff into the VFS is the initial soil water content factor (OI) needed by VFSMOD at the beginning of the simulation.

2.2. THETAFAO input files

All inputs for THETAFAO are in ASCII text and need to be present in the INPUTS directory before running the program. The EU FOCUS.MET file (typically R1NOIRR.MET, R2NOIRR.MET, etc.) is one of the standard .MET files, with two additional columns at the end, i.e. maximum and minimum daily temperatures (T_{min} and T_{max}, °C) used to estimate the daily minimum air relative humidity (RHmin %, eq. 13) needed in the calculations.

Note: The program inputs are contained in filename.IN ("filename" must match the name of the .MET file, i.e. R1NOIRR.IN, R2NOIRR.IN, etc.), as in the example above. A description of these files follows.

2.2.1 filename.IN (soil and vegetation parameters for estimating the daily soil water)

2.2.1.1 Structure of the input file

```
soiltype OI FC WP
ZR PFRAC HM
(iFM)
```

2.2.1.2 Definition

This file is written in FORTRAN free format:

soiltype USDA soil textural type, index from -1 to 9 (taken from Table 1)

-1 = user	5 = Silty Loam
1 = Sandy	6 = Silty
2 = Loamy Sand	7 = Silty Clay Loam
3 = Sandy Loam	8 = Silty Clay
4 = Loam	9 = Clay

If soiltype=-1 ("user" defined) the OI, FC and WP values in the first line are also read.

OI θ_i (m^3/m^3), Initial soil water content at the beginning of the simulation. It can set to field capacity for the first time step. This is the same as OI in VFSMOD input file (.ISO).

FC θ_{FC} (m^3/m^3), soil field capacity. For EU FOCUS R1-R4 scenarios this can be taken from parameters used by the PRZM model (see Appendix D and E). FAO recommendations based on soil type are included in Table 1 (FAO, 1998). For multilayer soil use the depth-weighted average value from the surface to the bottom of the root zone (ZR, see below).

WP — θ_{WP} (m^3/m^3), soil wilting point. For EU FOCUS R1-R4 scenarios this can be taken from parameters used by the PRZM model (see Appendix D and E). FAO recommendations based on soil type are included in Table 1 (FAO, 1998). For multilayer soil use the depth-weighted average value from the surface to the bottom of the root zone (ZR, see below).

ZR — Z_r (m), depth of buffer vegetation root zone. Typical value for mature VFS area 0.6-1.0 m from the range suggested by FAO (1998) (see Appendix C).

PFRAC — *p* (-), the fraction of the total soil available water that a crop can extract from the root zone without suffering water stress. For Bermuda grass *p*=0.6 is taken from the range suggested by FAO (1998) (see Appendix C).

HM — *h* (m), vegetation height. For VFS it is equivalent to H(/100) factor in VFSMOD, where H is the effective (rigid) vegetation height typically maintained by mowing the grass at a recommended height. Recommended values for grasses can be obtained from the VFSMOD manual appendix.

IFM — (if present). New in t*hetafao* v.06. Flag to specify the last columns of the .MET file for RH_{min} calculations and values of $K_{c,mid}$ when desired (if not, the default $K_{c,mid}$ = 1.0 for grass is used). Based on the iFM flag the number of columns the user must provide in the .MET file after the date field changes as:

iFM= 0 (or not present, DEFAULT for EU FOCUS) last two columns daily $TEMP_{min}$ and $TEMP_{max}$ (Celsius) used to calculate RH_{min} using Eq. 13 (8 columns)

iFM= 1, last column is RH_{min} (7 columns)

iFM= 2, last 3 columns are $TEMP_{min}$, $TEMP_{max}$, and variable K_{cmid} is given daily for a plant other than grass (9 columns)

iFM= 3, last 2 columns are RH_{min}, and variable $K_{c,mid}$ is given daily for a crop other than grass (8 columns)

2.2.1.3 Input file example file: R1NOIRR.IN

```
-1  0.23 0.275  0.1708
1.0 0.6 0.35
0
```

2.2.2 filename.MET (weather file from FOCUS shell application)

2.2.2.1 Structure of the input file (filename.MET)

The file has no headers, just numbers with their corresponding units as described below. The number of columns and the content of the last columns change with iFM given in the .IN file:

a) iFM = 0 (or not present)

```
MMDDYY  PRECIP   PEVP   TEMP  WIND2   SOLRAD   TMAX   TMIN
. . .
```

b) iFM = 1

```
MMDDYY  PRECIP   PEVP   TEMP  WIND2   SOLRAD   RHM
. . .
```

c) iFM = 2

```
MMDDYY  PRECIP   PEVP   TEMP  WIND2   SOLRAD   TMAX   TMIN   CKMID
. . .
```

d) iFM = 3

```
MMDDYY  PRECIP   PEVP   TEMP  WIND2   SOLRAD   RHM   CKMID
. . .
```

2.2.2.2 Definition

MMDDYY Calendar month/day/year. Important: to handle the particular EU FOCUS PRZM date formatting used in the original .MET files that contain blanks in the string chain, the date field must be formatted as A7 (i.e. with at least one space to the left of the field- see example). For example, if month or day have only one digit and the second is left blank, ' 1 378' (Jan 3, 1978) but ' 101175' (Oct. 11, 1975). Fixed format

PRECIP Daily precipitation (cm/day). Free format.

PEVP ETo based on daily pan (Class-A) evaporation (cm/day). Free format. Note: Class A evaporimeter readings should be converted already to ETo using the class-A pan coefficients in Appendix A.

TEMP Daily average temperature (Celsius). Free format.

WIND2 Daily average wind speed (cm/s) measured at 2 m above the ground. Fr Free format ee format.

SOLRAD Solar radiation (Langley/day). Free format.

TMAX Daily maximum air temperature (Celsius). Free format.

TMIN Daily minimum air temperature (Celsius). Free format.

RHM Daily minimum air relative humidity (RH_{min} ,%). Free format.

CKMID Mid-season crop coefficient (maximum), $K_{c,mid}$ (-). The value can be varied daily with a phenological curve during the season for the specific plant. Free format.

2.2.2.3 Input file example file: R1NOIRR.MET (*IFM* = 0 or not present)

```
   1 175      0.00      0.02       3.9       330      46.9      12.9       0.0
   1 275      0.00      0.02       3.4       110      40.4       9.8      -2.0
   1 375      0.00      0.03       2.7       150      40.7       9.4      -2.4
   1 475      0.00      0.04       2.0       390      41.0      10.2      -1.5
   1 575      0.02      0.03       2.7       470      47.3       8.0      -1.4
   1 675      0.00      0.04       4.6       540      43.5       7.4      -1.3
   1 775      0.73      0.08       4.8       660      42.0      10.4      -0.6
   1 875      0.02      0.02       3.2       330      67.4      13.8       5.1
   1 975      0.00      0.00      -0.2       120      96.1      11.5       4.1
   . . .
  122875      0.00      0.01       2.9       240      68.7      14.0       6.1
    . . .
```

2.2. THETAFAO output files

Two files with the same name as that use in the aplication run with extensions .OUT and .MET are created in the OUTPUT directory of the application. The first file contains a summary of the input factors and some intermediate values calculated from these. For the example application presented above the file R1NOIRR.OUT is created,

```
File: output/R1NOIRR.out                              THETAFAO v0.7, 11/2022

 TOP SOIL WATER CALCULATION FAO (1998) METHOD

 INPUTS
 ------
Soil type                                         =    User
Top soil field capacity, FC(m3/m3)                =    0.275
Top soil wilting point, WP(m3/m3)                 =    0.171
Top soil initial water content, OI(m3/m3)         =    0.230
Maximum grass root zone depth, Zr(m)              =    1.00
Fraction of easily extractable water,pfrac        =    0.60
Total available water, TAW(mm)                    =  104.20
Mid season crop coeff., Kcmid                     =    1.00
Vegetation height, H(m)                           =    0.35
Input format option for MET file, iFM = 0         =    last 2 columns Tmax,Tmin
```

The second output file is the original .MET file with the calculated topsoil water content and calculated ET_a added to <u>the last two columns</u>. For the example application in this appendix the following file R1NOIRR.MET is created,

```
   1 175     0.00     0.02      3.9     330.     46.9     12.90      0.00     0.230     0.021
   1 275     0.00     0.02      3.4     110.     40.4      9.80     -2.00     0.230     0.020
   1 375     0.00     0.03      2.7     150.     40.7      9.40     -2.40     0.229     0.030
   1 475     0.00     0.04      2.0     390.     41.0     10.20     -1.50     0.229     0.042
   1 575     0.02     0.03      2.7     470.     47.3      8.00     -1.40     0.229     0.031
   1 675     0.00     0.04      4.6     540.     43.5      7.40     -1.30     0.228     0.042
   1 775     0.73     0.08      4.8     660.     42.0     10.40     -0.60     0.235     0.087
   1 875     0.02     0.02      3.2     330.     67.4     13.80      5.10     0.235     0.020
   1 975     0.00     0.01     -0.2     120.     96.1     11.50      4.10     0.235     0.010
   11075     0.00     0.01      3.3     190.     60.4     12.60      2.20     0.235     0.010
   11175     0.00     0.01      2.9     240.     68.7     14.00      6.10     0.234     0.010
 . . .
```

<u>Note:</u> Examples for other iFM options in the .IN file and corresponding .MET files are provided in the distribution package under the inputs directory (iFM = 0 →test0, iFM = 1 →test1, iFM = 2 →test2, iFM = 3→test3; iFM = 2 and $K_{c,mid}$=0.5 →test25).

APPENDIX B - Pan coefficients (K pan) for class A pan evaporimeter

The values in the FOCUS .MET files for PEVP are assumed to be ETo adjusted based based on the pan coefficients provided below.

Table 4. Pan coefficient (K pan) for class A pan evaporimeter for different ground cover and levels of mean relative humidity and 24 hour wind

Class A pan	**Case A: Pan placed in short green cropped area**			
RH mean %		**low < 40**	**medium 40-70**	**high > 70**
Wind km/day	**Windward side distance of green crop (m)**			
Light	1	.55	.65	.75
< 175	10	.65	.75	.85
	100	.7	.8	.85
	1000	.75	.85	.85
Moderate	1	.5	.6	.65
175-425	10	.6	.7	.75
	100	.65	.75	.8
	1000	.7	.8	.8
Strong	1	.45	.5	.6
425-700	10	.55	.6	.65
	100	.6	.65	.7
	1000	.65	.7	.75
Very strong	1	.4	.45	.5
> 700	10	.45	.55	.6
	100	.5	.6	.65
	1000	.55	.6	.65

Source: Brouwer, C. and M. Heibloem. 1986. Irrigation Water Management. FAO Training manual no. 3. FAO: Rome.

APPENDIX C- Ranges of maximum effective rooting depth (Z_r), and soil water depletion fraction (p).

Table 5. Ranges of maximum effective rooting depth (Zr), and soil water depletion fraction for no stress (p), for common crops (Source: FAO-56)

Crop	Maximum Root Depth (m), Z_r	Depletion Fraction[2] (for ET =: 5 mm/day) p
j. Forages		
Alfalfa – for hay – for seed	1.0-2.0 1.0-3.0	0.55 0.60
Bermuda – for hay – Spring crop for seed	1.0-1.5 1.0-1.5	0.55 0.60
Clover hay, Berseem	0.6-0.9	0.50
Rye Grass hay	0.6-1.0	0.60
Sudan Grass hay (annual)	1.0-1.5	0.55
Grazing Pasture - Rotated Grazing	0.5-1.5 0.5-1.5	0.60 0.60
Turf grass - cool season[5] - warm season[5]	0.5-1.0 0.5-1.0	0.40 0.50

APPENDIX D- Soil parameters for the EU FOCUS scenarios for two typical VFS root zone depths (Z_r=0.6, 1.0 m).

Table 6. Soil parameters for the EU FOCUS scenarios for two typical VFS root zone depths (Z_r=0.6, 1.0 m)[1]

Scenario	*Values*	*Soil horizon* 1	2	3	4	*Z_r=0.6 m*	*Z_r=1.0 m*	%Δ
R1	depth (m)	0.30	0.30	0.40	--	--	--	--
	FC	0.338	0.286	0.277	--	0.312	0.298	4%
	WP	0.141	0.111	0.108	--	0.126	0.121	4%
R2	depth (m)	0.20	0.25	0.20	0.35	--	--	--
	FC	0.360	0.270	0.190	0.170	0.280	0.237	15%
	WP	0.180	0.140	0.100	0.080	0.143	0.119	17%
R3	depth (m)	0.45	0.30	0.70	0.15	--	--	--
	FC	0.37	0.35	0.36	0.36	0.365	0.362	1%
	WP	0.22	0.21	0.21	0.22	0.218	0.215	1%
R4	depth (m)	0.30	0.30	1.10	1.30	--	--	--
	FC	0.260	0.270	0.145	0.160	0.265	0.217	18%
	WP	0.160	0.160	0.060	0.070	0.160	0.120	25%

[1]These values are obtained by depth-weighted average of the soil horizon values for each R1-R4 soil. The original FOCUS PRZM values are included in Appendix E.

APPENDIX E - Soil and site parameters for EU FOCUS scenarios used in PRZM

Table 7. R1 soil and site parameters for PRZM (Table D-14 in EU FOCUS manual)

Horizon (FAO, 1990) Depth (cm)	Ap 0-30	Bw 30-60	BC 60-100+
BASIC PROPERTIES			
Sand (%)	5	6	5
Silt (%)	82	83	84
Clay (%)	13	11	11
Texture (FAO, 1990; USDA, 1999)	silt loam	silt loam	silt loam
Organic carbon (%)	1.2	0.3	0.1
Bulk density (g/cm^3)	1.35	1.45	1.48 [a]
PH	7.3	7.6	8.0
Structure (FAO, 1990)			
Development	Weak	Weak	Very weak
Size	Fine	Medium	Very coarse
Shape	Subangular blocky	Subangular blocky	Subangular blocky
HYDRAULIC PROPERTIES			
Field capacity (% volume)	33.8 [b]	28.6 [b]	27.7 [b]
Wilting point (% volume)	14.1 [b]	11.1 [b]	10.8 [b]

RUNOFF & SOIL LOSS PROPERTIES

Parameter	Value	Selection criteria	Reference
Hydrologic group (HGRP)	C	appropriate for soil type	FOCUS definition
USLE K factor (USLEK)	0.42	silt/silt loam, 2% OM	PRZM manual
USLE LS factor (USLELS)	0.33	45 m length, 3% slope	PRZM manual
USLE P factor (USLEP)	0.50	contouring, 3% slope	PRZM manual
Area of field (AFIELD)	0.45 ha	assumption for scenario	FOCUS definition
IREG	3	even monthly rain distrib.	FOCUS definition
Slope (SLP)	3%	appropriate for scenario	FOCUS definition
HL	20 m	assumption for scenario	FOCUS definition
Manning's coefficient	0.10	fallow, no-till or coulter	PRZM manual

[a] Estimated value using SSLRC algorithms and measured local data for the soil type.
[b] Calculated using PRZM pedo-transfer functions with other data given in the table (FC = –33 kPa; WP = –1500 kPa).

Table 8. R2 soil and site parameters for PRZM (Table D-15 in EU FOCUS manual)

Horizon (FAO, 1990) Depth (cm)	Ap 0-20	Ah 20-45	AB1 45-65	AB2 65-100
BASIC PROPERTIES				
Sand (%)	67	72	75	74
Silt (%)	19	16	13	16
Clay (%)	14	12	12	10
Texture (FAO, 1990; USDA, 1999)	sandy loam	sandy loam	sandy loam	sandy loam
Organic carbon (%)	4.0	2.4	0.8	0.5 [a]
Bulk density (g/cm^3)	1.15 [b]	1.29 [b]	1.36 [b]	1.41 [b]
pH	4.5	4.9	5.4	5.3
Structure (FAO, 1990)				
Development	Moderate	Weak	Weak	Weak
Size	Medium	Medium	Medium	Medium
Shape	Subangular blocky	Subangular blocky	Subangular blocky	Subangular blocky
HYDRAULIC PROPERTIES				
Field capacity (% volume)	36 [c]	27 [c]	19 [c]	17 [c]
Wilting point (% volume)	18 [c]	14 [c]	10 [c]	8 [c]

RUNOFF & SOIL LOSS PROPERTIES

Parameter	Value	Selection criteria	Reference
Hydrologic group (HGRP)	B / C	appropriate for soil type	FOCUS definition
USLE K factor (USLEK)	0.19	sandy loam, 4% OM	PRZM manual
USLE LS factor (USLELS)	0.66	45 m length, 5% slope	PRZM manual
USLE P factor (USLEP)	0.50	contouring, 5% slope	PRZM manual
Area of field (AFIELD)	0.45 ha	assumption for scenario	FOCUS definition
IREG	2	heavier winter rain	FOCUS definition
Slope (SLP)	5%	20% slope, terraced to 5%	FOCUS definition
HL	20 m	assumption for scenario	FOCUS definition
Manning's coefficient	0.10	fallow, no-till or coulter	PRZM manual

[a] Estimated value based on horizon type and value for horizon above.
[b] Estimated value using SSLRC algorithms and measured local data for the soil type.
[c] Calculated using PRZM pedo-transfer functions with other data given in the table (FC = –33 kPa; WP = –1500 kPa).

Table 9. R3 soil and site parameters for PRZM (Table D-16 in EU FOCUS manual)

Horizon (FAO, 1990) Depth (cm)	Ap1 0 – 45	Ap2 45 - 75	Bk 75 – 145	C 145 – 160
BASIC PROPERTIES				
Sand (%)	23	25	17	14
Silt (%)	43	42	48	50
Clay (%)	34	33	35	36
Texture (FAO, 1990; USDA, 1999)	clay loam	clay loam	silty clay loam	silty clay loam
Organic carbon (%)	1.0	1.0	0.35	0.29
Bulk density (g/cm^3)	1.46[a]	1.49[a]	1.52[a]	1.54[a]
pH	7.9	7.9	8.3	8.6
Structure (FAO, 1990)				
Development	Moderate	Moderate	Weak	Weak
Size	fine	Fine	coarse	Very coarse
Shape	Granular	granular	Subangular blocky	Angular blocky
HYDRAULIC PROPERTIES				
Field capacity (% volume)	37 [b]	35 [b]	36 [b]	36 [b]
Wilting point (% volume)	22 [b]	21 [b]	21 [b]	22 [b]

RUNOFF & SOIL LOSS PROPERTIES

Parameter	Value	Selection criteria	Reference
Hydrological group (HGRP)	C	appropriate for soil type	FOCUS definition
USLE K factor (USLEK)	0.25	clay loam, 1% OM	PRZM manual
USLE LS factor (USLELS)	0.66	45 m length, 5% slope	PRZM manual
USLE P factor (USLEP)	0.50	contouring, 5% slope	PRZM manual
Area of field (AFIELD)	0.45 ha	assumption for scenario	FOCUS definition
IREG	3	even seasonal rain	FOCUS definition
Slope (SLP)	5%	10% slope, terraced to 5%	FOCUS definition
HL	20 m	assumption for scenario	FOCUS definition
Manning's coefficient	0.10	fallow, no-till or coulter	PRZM manual

[a] Estimated using SSLRC pedo-transfer functions with other data given in the table and checked against data in the PRZM manual.
[b] Calculated using PRZM pedo-transfer functions with other data given in the table (FC = –33 kPa; WP = –1500 kPa).

Table 10. R4 soil and site parameters for PRZM (Table D-17 in EU FOCUS manual)

Horizon (FAO, 1990) Depth (cm)	Ap1 0-30	Ap2 30-60	2C1 60 - 170	2C2 170-300
BASIC PROPERTIES				
Sand (%)	53	53	69	65
Silt (%)	22	22	24	27
Clay (%)	25	25	7	8
Texture (FAO, 1990; USDA, 1999)	sandy clay loam	sandy clay loam	sandy loam	sandy loam
Organic carbon (%)	0.6	0.6 [a]	0.08	0.08
Bulk density (g/cm^3)	1.52	1.50 [a]	1.49	1.50
pH	8.4	8.4 [a]	8.8	8.8
Structure (FAO, 1990)				
Development	Moderate	Moderate	Apedal	Apedal
Size	Fine	Fine	N/A	N/A
Shape	Subangular blocky	Subangular blocky	Single grain	Single grain
HYDRAULIC PROPERTIES				
Field capacity (% volume)	26 [b]	27 [b]	14.5 [b]	16 [b]
Wilting point (%volume)	16 [b]	16 [b]	6 [b]	7 [b]
RUNOFF & SOIL LOSS PROPERTIES				
Parameter	**Value**	**Selection criteria**		**Reference**
Hydrologic group (HGRP)	C	appropriate for soil type		FOCUS definition
USLE K factor(USLEK)	0.26	sandy clay loam, 0.6% OM		PRZM manual
USLE LS factor (USLELS)	0.66	45 m length, 5% slope		PRZM manual
USLE P factor (USLEP)	0.50	contouring, 5% slope		PRZM manual
Area of field (AFIELD)	0.45 ha	assumption for scenario		FOCUS definition
IREG	2	heavier winter rain		FOCUS definition
Slope (SLP)	5%	appropriate for scenario		FOCUS definition
HL	20 m	assumption for scenario		FOCUS definition
Manning's coefficient	0.10	fallow, no-till or coulter		PRZM manual

[a] Estimated value based on horizon type and value for horizon above.
[b] Calculated using PRZM pedo-transfer functions with other data given in the table (FC = –33 kPa; WP = –1500 kPa).

APPENDIX F - Table of results for example application

Detailed calculations for the example contained in the text of the report are provided here with reference to the equations used in the calculations.

Julian	P(mm) (data)	ETo-A(mm) (data)	u2(m/s) (data)	RHmin(%) (eq.13)	Kcb (eq.4)	ETc(mm/h) (eq.3)	p (eq.8)	RAW (mm) (eq.7)	$D_{r,i-1}$ (mm) (eq.9-10)	$D_{r,i}$ (mm) (eq.10)	DPi (mm) (eq.11)	Ks (eq.5)	ETa(mm/d) (eq.3)	θ_{Zr} (m^3/m^3) (eq.12)
1	0	0.2	3.3	41.134	1.035	0.207	0.792	82.497	45	45.207	0	1	0.207	0.23
2	0	0.2	1.1	43.632	0.984	0.197	0.792	82.54	45.207	45.404	0	1	0.197	0.23
3	0	0.3	1.5	43.515	0.993	0.298	0.788	82.119	45.404	45.702	0	1	0.298	0.229
4	0	0.4	3.9	44.072	1.042	0.417	0.783	81.623	45.702	46.118	0	1	0.417	0.229
5	0.2	0.3	4.7	51.49	1.043	0.313	0.787	82.056	46.118	46.231	0	1	0.313	0.229
6	0	0.4	5.4	54.034	1.052	0.421	0.783	81.605	46.231	46.652	0	1	0.421	0.228
7	7.3	0.8	6.6	46.447	1.094	0.875	0.765	79.714	46.652	40.227	0	1	0.875	0.235
8	0.2	0.2	3.3	55.725	1.005	0.201	0.792	82.522	40.227	40.228	0	1	0.201	0.235
9	0	0.1	1.2	60.417	0.951	0.095	0.796	82.964	40.228	40.323	0	1	0.095	0.235
10	0	0.1	1.9	49.135	0.989	0.099	0.796	82.948	40.323	40.422	0	1	0.099	0.235
11	0	0.1	2.4	58.953	0.979	0.098	0.796	82.952	40.422	40.52	0	1	0.098	0.234
12	0.5	0.2	2.1	59.552	0.972	0.194	0.792	82.55	40.52	40.214	0	1	0.194	0.235
13	0	0.1	2.7	49.514	1.005	0.101	0.796	82.941	40.214	40.315	0	1	0.101	0.235
14	0	0.1	1.6	73.262	0.932	0.093	0.796	82.971	40.315	40.408	0	1	0.093	0.235
15	0	0.3	1.6	74.09	0.931	0.279	0.789	82.196	40.408	40.687	0	1	0.279	0.234
16	0	0.2	1.4	80.528	0.913	0.183	0.793	82.599	40.687	40.87	0	1	0.183	0.234
17	6.2	0.2	4.1	50.333	1.033	0.207	0.792	82.499	40.87	34.876	0	1	0.207	0.24
18	6.2	0.4	2.7	66.477	0.97	0.388	0.784	81.743	34.876	29.064	0	1	0.388	0.246
19	2	0.3	1.3	57.821	0.958	0.288	0.788	82.162	29.064	27.352	0	1	0.288	0.248
20	1.1	0.1	1.3	41.382	0.993	0.099	0.796	82.946	27.352	26.351	0	1	0.099	0.249
21	0.1	0.5	4.1	58.884	1.015	0.507	0.78	81.245	26.351	26.758	0	1	0.507	0.248
22	1.6	0.4	5.8	47.583	1.074	0.43	0.783	81.569	26.758	25.588	0	1	0.43	0.249
23	1	0.7	6.1	62.398	1.05	0.735	0.771	80.298	25.588	25.323	0	1	0.735	0.25
24	4.9	0.5	4.3	56.428	1.024	0.512	0.78	81.225	25.323	20.935	0	1	0.512	0.254
25	2.4	0.6	4.9	44.998	1.061	0.637	0.775	80.707	20.935	19.172	0	1	0.637	0.256
26	0	0.2	2.8	48.62	1.009	0.202	0.792	82.519	19.172	19.373	0	1	0.202	0.256
27	9.8	0.3	3.5	48.432	1.024	0.307	0.788	82.079	19.373	9.881	0	1	0.307	0.265
28	3.6	0.7	5.9	51.71	1.068	0.747	0.77	80.245	9.881	7.028	0	1	0.747	0.268
29	2.8	0.5	5.7	54.047	1.059	0.529	0.779	81.154	7.028	4.758	0	1	0.529	0.27
30	1.1	0.3	3.7	47.671	1.03	0.309	0.788	82.072	4.758	3.967	0	1	0.309	0.271
31	5	0.3	2.5	48.37	1.003	0.301	0.788	82.105	3.967	0	0.732	1	0.301	0.275
32	3.5	0.6	2.6	52.538	0.997	0.598	0.776	80.867	0	0	2.902	1	0.598	0.275
33	0	0.3	1.7	50.891	0.981	0.294	0.788	82.133	0	0.294	0	1	0.294	0.275
34	0	0.8	5	47.643	1.057	0.846	0.766	79.834	0.294	1.14	0	1	0.846	0.274

35	0	0.7	5.2	59.154	1.037	0.726	0.771	80.333	1.14	1.867	0	1	0.726	0.273
36	0	0.2	2.6	75.414	0.949	0.19	0.792	82.569	1.867	2.056	0	1	0.19	0.273
37	0	0.1	2	64.676	0.959	0.096	0.796	82.96	2.056	2.152	0	1	0.096	0.273
38	0	0.1	0.8	58.868	0.946	0.095	0.796	82.966	2.152	2.247	0	1	0.095	0.273
39	0	0.2	2.2	54.377	0.985	0.197	0.792	82.539	2.247	2.444	0	1	0.197	0.273
40	0	0.2	1.3	64.545	0.944	0.189	0.792	82.573	2.444	2.633	0	1	0.189	0.272
41	0	0.1	1.2	64.085	0.943	0.094	0.796	82.967	2.633	2.727	0	1	0.094	0.272
42	0.1	0.2	0.9	72.536	0.919	0.184	0.793	82.594	2.727	2.811	0	1	0.184	0.272
43	0.7	0.4	2.1	72.9	0.944	0.377	0.785	81.787	2.811	2.488	0	1	0.377	0.273
44	1.6	0.5	3.3	50.033	1.017	0.508	0.78	81.241	2.488	1.396	0	1	0.508	0.274
45	0.1	0.7	3.7	54.771	1.015	0.711	0.772	80.398	1.396	2.007	0	1	0.711	0.273
46	0.1	0.5	2.2	57.492	0.978	0.489	0.78	81.322	2.007	2.396	0	1	0.489	0.273
47	0	0.6	3.3	49.33	1.018	0.611	0.776	80.814	2.396	3.007	0	1	0.611	0.272
48	0.1	0.2	1	39.349	0.991	0.198	0.792	82.534	3.007	3.105	0	1	0.198	0.272
49	0.8	0.5	1.3	33.19	1.01	0.505	0.78	81.255	3.105	2.81	0	1	0.505	0.272
50	19.6	0.6	3.3	31.138	1.056	0.634	0.775	80.718	2.81	0	16.156	1	0.634	0.275
51	0	0.8	3.3	44.62	1.028	0.822	0.767	79.932	0	0.822	0	1	0.822	0.274
52	0	0.7	3.1	38.349	1.037	0.726	0.771	80.334	0.822	1.548	0	1	0.726	0.273
53	0	0.4	1.2	72.113	0.926	0.371	0.785	81.816	1.548	1.919	0	1	0.371	0.273
54	0	0.4	1	50.223	0.968	0.387	0.785	81.746	1.919	2.306	0	1	0.387	0.273
55	0	0.6	1.4	44.653	0.988	0.593	0.776	80.889	2.306	2.899	0	1	0.593	0.272
56	0	0.9	3.8	35.597	1.058	0.952	0.762	79.393	2.899	3.851	0	1	0.952	0.271
57	0	1	3.5	33.938	1.055	1.055	0.758	78.964	3.851	4.906	0	1	1.055	0.27
58	0	0.8	2	36.833	1.017	0.814	0.767	79.968	4.906	5.719	0	1	0.814	0.269
59	0	0.6	1	46.924	0.975	0.585	0.777	80.922	5.719	6.304	0	1	0.585	0.269
60	0	0.6	0.3	52.261	0.949	0.569	0.777	80.987	6.304	6.874	0	1	0.569	0.268
61	1.2	0.9	2	65.473	0.957	0.861	0.766	79.77	6.874	6.535	0	1	0.861	0.268
62	3.2	1	2.2	69.914	0.952	0.952	0.762	79.393	6.535	4.287	0	1	0.952	0.271
63	0.1	1	2.5	47.975	1.004	1.004	0.76	79.174	4.287	5.191	0	1	1.004	0.27
64	0.2	1	2.9	53.202	1.002	1.002	0.76	79.185	5.191	5.993	0	1	1.002	0.269
65	0.1	0.9	2.6	41.387	1.02	0.918	0.763	79.533	5.993	6.811	0	1	0.918	0.268
66	4.9	1	3.5	51.268	1.018	1.018	0.759	79.116	6.811	2.929	0	1	1.018	0.272
67	0.1	1.2	2.4	48.627	1.001	1.201	0.752	78.354	2.929	4.03	0	1	1.201	0.271
68	1.8	0.9	2.2	59.405	0.974	0.877	0.765	79.707	4.03	3.107	0	1	0.877	0.272
69	0.3	0.8	2.4	56.786	0.984	0.787	0.769	80.08	3.107	3.594	0	1	0.787	0.271
70	0	0.8	1.2	64.771	0.942	0.753	0.77	80.22	3.594	4.347	0	1	0.753	0.271
71	0.3	1.1	5.2	63.517	1.028	1.131	0.755	78.645	4.347	5.178	0	1	1.131	0.27
72	6.2	1	4.8	69.937	1.006	1.006	0.76	79.165	5.178	0	0.015	1	1.006	0.275
73	0.4	0.8	1.7	67.247	0.947	0.758	0.77	80.202	0	0.358	0	1	0.758	0.275
74	0	0.7	1.8	54.362	0.976	0.683	0.773	80.512	0.358	1.041	0	1	0.683	0.274
75	0.9	0.9	2.4	59.405	0.978	0.88	0.765	79.691	1.041	1.021	0	1	0.88	0.274

76	0	1	2.2	45.844	1.002	1.002	0.76	79.182	1.021	2.024	0	1	1.002	0.273
77	12.6	1.1	6.6	57.207	1.071	1.178	0.753	78.45	2.024	0	9.398	1	1.178	0.275
78	13.3	0.8	3.9	54.538	1.02	0.816	0.767	79.959	0	0	12.484	1	0.816	0.275
79	0.4	1	2.7	56.483	0.991	0.991	0.76	79.231	0	0.591	0	1	0.991	0.274
80	0.2	1.3	3.3	49.431	1.018	1.323	0.747	77.844	0.591	1.714	0	1	1.323	0.273
81	0	1	1.1	50.47	0.97	0.97	0.761	79.319	1.714	2.684	0	1	0.97	0.272
82	0	1.3	1.3	55.231	0.964	1.253	0.75	78.138	2.684	3.937	0	1	1.253	0.271
83	3.7	0.9	4.2	57.143	1.021	0.919	0.763	79.531	3.937	1.155	0	1	0.919	0.274
84	0.3	1.1	5.1	54.677	1.045	1.149	0.754	78.57	1.155	2.004	0	1	1.149	0.273
85	0.3	1.3	5.4	44.502	1.072	1.394	0.744	77.549	2.004	3.099	0	1	1.394	0.272
86	2.4	1.2	3.9	54.651	1.02	1.224	0.751	78.26	3.099	1.922	0	1	1.224	0.273
87	0.5	1.7	5.7	62.624	1.041	1.769	0.729	75.986	1.922	3.191	0	1	1.769	0.272
88	0	1.4	2.7	58.684	0.986	1.38	0.745	77.607	3.191	4.572	0	1	1.38	0.27
89	0	1.1	1.2	54.868	0.962	1.059	0.758	78.947	4.572	5.63	0	1	1.059	0.269
90	0	1.3	2.7	53.293	0.997	1.296	0.748	77.956	5.63	6.927	0	1	1.296	0.268
91	0	1.3	1	54.419	0.959	1.247	0.75	78.163	6.927	8.174	0	1	1.247	0.267
92	2.5	1	3.2	47.301	1.02	1.02	0.759	79.107	8.174	6.694	0	1	1.02	0.268
93	9	1	3.2	57.768	0.998	0.998	0.76	79.199	6.694	0	1.307	1	0.998	0.275
94	0.1	1.3	2.1	55.098	0.981	1.275	0.749	78.045	0	1.175	0	1	1.275	0.274
95	0.5	1.3	1.6	56.387	0.968	1.258	0.75	78.117	1.175	1.933	0	1	1.258	0.273
96	1.9	0.9	1.7	51.844	0.979	0.881	0.765	79.686	1.933	0.915	0	1	0.881	0.274
97	2.7	1.5	2.5	51.625	0.997	1.495	0.74	77.129	0.915	0	0.291	1	1.495	0.275
98	3.2	2.1	6.8	41.841	1.107	2.326	0.707	73.667	0	0	0.874	1	2.326	0.275
99	0.6	1.8	3.7	61.342	1.001	1.802	0.728	75.847	0	1.202	0	1	1.802	0.274
100	1.1	1.3	2.4	51.75	0.994	1.292	0.748	77.973	1.202	1.395	0	1	1.292	0.274
101	0.1	1.3	3.3	44.301	1.029	1.337	0.747	77.786	1.395	2.632	0	1	1.337	0.272
102	1.9	1.2	4.2	45.533	1.045	1.254	0.75	78.133	2.632	1.986	0	1	1.254	0.273
103	0	1.4	3.6	38.837	1.047	1.465	0.741	77.253	1.986	3.452	0	1	1.465	0.272
104	3.1	1.6	2.9	33.384	1.043	1.669	0.733	76.403	3.452	2.021	0	1	1.669	0.273
105	8	1.8	5.4	48.744	1.064	1.914	0.723	75.381	2.021	0	4.065	1	1.914	0.275
106	0.7	1.8	4	56.159	1.019	1.833	0.727	75.718	0	1.133	0	1	1.833	0.274
107	0.2	1.5	1.3	48.253	0.978	1.468	0.741	77.243	1.133	2.401	0	1	1.468	0.273
108	0	2.3	2	45.573	0.999	2.297	0.708	73.785	2.401	4.698	0	1	2.297	0.27
109	0	2.2	2.2	57.949	0.977	2.149	0.714	74.401	4.698	6.848	0	1	2.149	0.268
110	4.4	1.5	1.7	45.773	0.992	1.488	0.74	77.158	6.848	3.936	0	1	1.488	0.271
111	0	2.1	1	47.27	0.974	2.046	0.718	74.833	3.936	5.982	0	1	2.046	0.269
112	0	3.1	2.3	41.219	1.014	3.144	0.674	70.255	5.982	9.126	0	1	3.144	0.266
113	0	3.3	2.6	47.488	1.007	3.324	0.667	69.504	9.126	12.45	0	1	3.324	0.263
114	0	3.1	3.6	46.238	1.031	3.196	0.672	70.039	12.45	15.646	0	1	3.196	0.259
115	0	3.5	4	36.031	1.061	3.713	0.651	67.885	15.646	19.359	0	1	3.713	0.256
116	0	2.5	1.9	40.023	1.008	2.521	0.699	72.853	19.359	21.88	0	1	2.521	0.253

117	0	2.9	1.4	41.215	0.995	2.887	0.685	71.329	21.88	24.767	0	1	2.887	0.25
118	0	3.2	1.3	41.38	0.993	3.177	0.673	70.117	24.767	27.944	0	1	3.177	0.247
119	0	3.8	2.5	43.773	1.013	3.85	0.646	67.315	27.944	31.794	0	1	3.85	0.243
120	0	2.5	2.8	42.072	1.023	2.557	0.698	72.701	31.794	34.351	0	1	2.557	0.241
121	0	3	0.9	36.422	0.995	2.985	0.681	70.92	34.351	37.336	0	1	2.985	0.238
122	0	3	1.3	33.889	1.009	3.026	0.679	70.748	37.336	40.362	0	1	3.026	0.235
123	7.5	2.1	3.7	40.14	1.046	2.196	0.712	74.205	40.362	35.058	0	1	2.196	0.24
124	0.1	2	6.1	62.855	1.049	2.097	0.716	74.619	35.058	37.055	0	1	2.097	0.238
125	12.4	2.9	7.5	54.351	1.096	3.178	0.673	70.114	37.055	27.833	0	1	3.178	0.247
126	3.7	2.4	4.1	46.793	1.04	2.497	0.7	72.953	27.833	26.63	0	1	2.497	0.248
127	0.2	3.6	3.2	50.264	1.014	3.651	0.654	68.143	26.63	30.081	0	1	3.651	0.245
128	1.2	1.9	1	58.491	0.951	1.806	0.728	75.831	30.081	30.687	0	1	1.806	0.244
129	3.3	2.8	2.8	55.957	0.994	2.783	0.689	71.762	30.687	30.17	0	1	2.783	0.245
130	0	2.6	3.1	60.705	0.99	2.574	0.697	72.63	30.17	32.744	0	1	2.574	0.242
131	0	2.4	2.4	81.038	0.933	2.239	0.71	74.03	32.744	34.983	0	1	2.239	0.24
132	0	3.4	3.2	57.71	0.999	3.395	0.664	69.21	34.983	38.378	0	1	3.395	0.237
133	0	3.3	1.2	45.545	0.982	3.241	0.67	69.852	38.378	41.618	0	1	3.241	0.233
134	0.3	3.1	2.3	52.972	0.99	3.068	0.677	70.574	41.618	44.386	0	1	3.068	0.231
135	0.3	3.1	2	41.805	1.007	3.121	0.675	70.353	44.386	47.207	0	1	3.121	0.228
136	0.1	2.5	1.1	57.11	0.956	2.389	0.704	73.402	47.207	49.496	0	1	2.389	0.226
137	0	3.6	1.7	51.524	0.98	3.528	0.659	68.655	49.496	53.024	0	1	3.528	0.222
138	15.4	3.4	1.2	40.911	0.992	3.372	0.665	69.305	53.024	40.996	0	1	3.372	0.234
139	0	3.8	2.9	51.065	1.006	3.823	0.647	67.424	40.996	44.819	0	1	3.823	0.23
140	0	4	2.6	44.432	1.014	4.055	0.638	66.458	44.819	48.875	0	1	4.055	0.226
141	0	4.7	2.8	45.898	1.015	4.77	0.609	63.478	48.875	53.645	0	1	4.77	0.221
142	0	4.2	3.6	49.441	1.024	4.302	0.628	65.43	53.645	57.947	0	1	4.302	0.217
143	0	3.5	3.7	61.005	1.002	3.507	0.66	68.742	57.947	61.454	0	1	3.507	0.214
144	1	3.7	3.5	58.981	1.002	3.708	0.652	67.905	61.454	64.162	0	1	3.708	0.211
145	0.6	2.6	3.7	57.995	1.008	2.622	0.695	72.432	64.162	66.184	0	1	2.622	0.209
146	0.4	3.3	5.7	54.489	1.058	3.491	0.66	68.811	66.184	69.274	0	0.987	3.445	0.206
147	0.8	2.2	3.2	47.759	1.019	2.243	0.71	74.012	69.274	70.717	0	1	2.243	0.204
148	0	3.5	2	56.66	0.976	3.414	0.663	69.129	70.717	74.131	0	0.857	2.927	0.201
149	1	3.8	1.9	62.665	0.961	3.651	0.654	68.142	74.131	76.782	0	0.76	2.776	0.198
150	4.1	2	2.7	46.211	1.012	2.024	0.719	74.923	76.782	74.707	0	1	2.024	0.2
151	1.4	2.1	2.1	63.101	0.964	2.025	0.719	74.921	74.707	75.331	0	0.986	1.996	0.2
152	0	2.9	2.8	71.852	0.96	2.785	0.689	71.751	75.331	78.117	0	0.804	2.239	0.197
153	2.2	2.6	2.7	52.447	0.999	2.598	0.696	72.533	78.117	78.514	0	0.811	2.107	0.196
154	0.1	3.7	5.8	51.043	1.067	3.948	0.642	66.904	78.514	82.362	0	0.586	2.312	0.193

…

APPENDIX G - THETAFAO v0.7 -Source code

```
      program thetafao
C----------------------------------------------------------------
c      version 0.7, Last Modified 11/14/2022
C      WRITTEN FOR: EU FOCUS PRZM/VFSMOD tool
C      Written by: R. Munoz-Carpena (rmc)
C                  University of Florida, carpena@ufl.edu
C----------------------------------------------------------------
C Program to calculate soil moisture content between runoff events.
C This is a necessary step for continuous simulation of the PRZM/VFSMOD
C EU FOCUS tool. The result of the calculation will produce the initial
C moisture content of the soil (OI) for the next VFSMOD run in the time
C series. It follows FAO-56 adjusted ET calculations (Allen et al.,1998)
C based on Dr. M. Qußemada (U. Politecnica Madrid) spreadsheet calculations
C and good results in the comparison with field measured soil moisture.
c----------------------------------------------------------------
C   Input parameters
c   isoiltype (USDA, S:Sand;L:Loam;s:Silt;C:Clay):-1:user,1:S,2:LS,3:SL,4:L,5:sL,6:s,7:sCL,8:sC,9:C
c   OI(m3/m3): top soil initial water content (same as in VFSMOD *.iso file)
c    FC(m3/m3): top soil fied capacity water content (read internally or provided by user when
isoiltype=-1)
c    WP(m3/m3): top soil wilting point water content (read internally or provided by user when
isoiltype=-1)
c   Zr(m): maximum grass root zone depth (typical values (0.5-1.5 m)
c   pfrac[-]: fraction of easily estractable water (typical 0.6 for Bermuda grass)
c   Hm(m): height of vegetation (from VFSMOD *.igr file, H(cm)/100)
c   iFH(optional): input MET file formating flag where,
C     iFM= 0 (or not present), 8 columns,last two columns are Tmin,Tmax
C     iFM= 1, 7 columns, last column is HRmean
C     iFM= 2, 9 columns, last 3 columns are Tmin,Tmax, Kcmid for a crop other than grass
C     iFM= 3, 8 columns, last 2 columns are HRmin, Kcmid for a crop other than grass
c   REW(mm): readily extractable water (soil dependent)
c   soil(isoiltype,1): FC, top soil field capacity (m3/m3)
c   soil(isoiltype,2): WP, top soil wilting point (m3/m3)
c   soil(isoiltype,1): top soil REW(mm) (see above)
c   TAW(mm): total available water
C----------------------------------------------------------------
c    Compiling for Win32 and Unix environments:
c       1. The i/o for these operating systems is different.
c       2. Change the comments in the finput.f program to reflect
c          your operating system.   3/9/2012
c----------------------------------------------------------------
c    CHANGES
c    v0.7, 11/14/2022. Added AET (mm) to last column of modified .MET output file and fix field
c      length for date that was short of 1 character on the output .MET file
c    v0.6, 12/19/2019. Changed iRH into iFM (input formatting MET)
c      to modify the last columns of the MET file with user cKmid
c----------------------------------------------------------------

      implicit double precision (a-h, o-z)
      CHARACTER*75 LISFIL(6)

c------------------------------------------
c  open files and get inputs
c------------------------------------------
      call finput(lisfil)
      call getinp(isoiltype,OI,FC,WP,Zr,pfrac,Hm,TAW,cKmid,iFM)
c--------------------------
c Calculate runoff volume by SCS method
c--------------------------
      call theta10(OI,Zr,pfrac,Hm,cKmid,WP,FC,iFM)
c--------------------------
c Output results
c--------------------------
      call  results(isoiltype,OI,FC,WP,Zr,pfrac,Hm,TAW,cKmid,iFM)
c----------
c Output message at end of program -----------------
c----------
      WRITE(*,*)
      WRITE(*,*)'...FINISHED!...'
```

```
      WRITE(*,*)


      close(1)
      close(2)
      close(3)
      close(4)

      stop
      end


      SUBROUTINE FINPUT(LISFIL)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     Create input and output file names from a command line input string    C
C     NOTE: Maximum length of command line string = 50                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      CHARACTER*50 FILENM1
      CHARACTER*75 LISFIL(6)
      CHARACTER*3,SCOD(6)
      CHARACTER*1,DUMMY1
      character*200 linein
      character*1 slash
      DATA(SCOD(I),I=1,3)/'in','met','out'/

c*** Command line option to input filename
c*** Comment out the following depending for which system you compile

CWIN32*** Start of Win32 file i/o     ***
CWIN32      slash='\'
CWIN32      INARGS=NARGS()-1
CWIN32      IF (INARGS.EQ.1) THEN
CWIN32      CALL GETARG(1,FILENM1,IFSTATUS)
CWIN32*** End of Win32 file i/o       ***
cUNIX *** Start Unix file i/o         ***
CUNIX
      slash='/'
CUNIX
      INARGS=IARGC()
CUNIX
      IF (INARGS.EQ.1) THEN
CUNIX
         CALL GETARG(1,FILENM1)
cUNIX *** End of UNIX file i/o section ***
       ELSE
         WRITE(*,*)
         WRITE(*,105)
         WRITE(*,110)
         WRITE(*,130)
         WRITE(*,140)
         WRITE(*,150)
         WRITE(*,*)
         STOP
      ENDIF
c----------
c Output message at end of program -----------------
c----------
      WRITE(*,*)
      WRITE(*,*)'THETAFAO v0.7, 11/2022'
      WRITE(*,*)'R.Munoz-Carpena (UFL), carpena@ufl.edu'
      WRITE(*,*)

C------ create I/O filenames from input string -------------------------
c------    or read filenames from a project file -----------------------
c
      ilstr=index(filenm1,'.')
      if (ilstr.gt.0) then
c      *** using project file (.prj or .lis) to read filenames
c      ***  check to see if extension is .prj or .lis
```

```
          ilstr1=index(filenm1,'.prj')
          ilstr2=index(filenm1,'.lis')
          if ((ilstr1.gt.0).or.(ilstr2.gt.0)) then
c          *** fill filename array with safe names
             do 11 i=1,3
               dummy1=scod(i)
               IF(DUMMY1.EQ.'i') THEN
                   WRITE(LISFIL(I),'(5A)')
     &             'inputs',slash,'dummy','.',SCOD(I)
                  ELSE
                   WRITE(LISFIL(I),'(5A)')
     &             'output',slash,'dummy','.',SCOD(I)
               ENDIF
11           continue
c
             open(unit=99,file=filenm1,status='old')
12           read(99,'(a)',end=18) linein
             lpos=index(linein,'=')
             lstr=len(linein)
             if ((lpos.gt.0).and.(lstr.gt.0)) then
                do 14 jj=1,3
                   lpp = index(linein(1:lpos-1),scod(jj))
                   if (lpp.gt.0) lisfil(jj)=linein(lpos+1:)
14              continue
             endif
             go to 12
c           ****** done
18           continue
            else
             WRITE(*,*)
             WRITE(*,105)
             WRITE(*,110)
             WRITE(*,130)
             WRITE(*,140)
             WRITE(*,150)
             WRITE(*,*)
             STOP
          endif
        else
c     **** rafa's i/o scheme
          ILSTR=INDEX(FILENM1,' ')-1
          DO 101 I=1,3
            DUMMY1=SCOD(I)
            IF(DUMMY1.EQ.'i'.or.DUMMY1.EQ.'m') THEN
                  WRITE(LISFIL(I),'(5A)')
     &        'inputs',slash,FILENM1(:ILSTR),'.',SCOD(I)
               ELSE
                  WRITE(LISFIL(I),'(5A)')
     &        'output',slash,FILENM1(:ILSTR),'.',SCOD(I)
            ENDIF
c--- recreate .MET file in output directory
            WRITE(LISFIL(4),'(5A)')
     &        'output',slash,FILENM1(:ILSTR),'.',SCOD(2)
101      CONTINUE
      endif

      write(*,*)'...Opening files...'
      DO 102 I=1,4
         write(*,'(70A)')lisfil(i)
102   CONTINUE

C---------Open I/O files -------------------------------
      OPEN(1,FILE=LISFIL(1),STATUS='OLD')
      OPEN(2,FILE=LISFIL(2),STATUS='OLD')
      OPEN(3,FILE=LISFIL(3),STATUS='unknown')
      OPEN(4,FILE=LISFIL(4),STATUS='unknown')
      WRITE(3,220)LISFIL(3)

105   FORMAT('Name:    thetafao')
110   FORMAT(9x,'(VFSMOD-FOCUS:calculate soil moisture between events)')
130   FORMAT('Usage:   thetafao filename (max 8 characters, no ext.)')
```

```
CWIN32
140   FORMAT('Version: 0.7 for Windows -Nov 2022')
CUNIX140   FORMAT('Version: 0.7 for Unix -Nov 2022')
150   FORMAT('Author: R.Munoz-Carpena (UFL), carpena@ufl.edu')
160   FORMAT(72('-'))
220   FORMAT('File: ',A40,9x,'THETAFAO v0.7, 11/2022')

      RETURN
      END


      subroutine getinp(isoiltype,OI,FC,WP,Zr,pfrac,Hm,
     & TAW,cKmid,iFM)
C-----------------------------------------------------------------
C   Input parameters
c   isoiltype (USDA, S:Sand;L:Loam;s:Silt;C:Clay):-1:user,1:S,2:LS,3:SL,4:L,5:sL,6:s,7:sCL,8:sC,9:C
c   OI(m3/m3): top soil initial water content (same as in VFSMOD *.iso file)
c   FC,soil(isoiltype,1): top soil field capacity (m3/m3)
c   WP,soil(isoiltype,2): top soil wilting point (m3/m3)
c   REW(mm): readily extractable water (soil dependent)
c   Zr(m): maximum grass root zone depth (typical values (0.5-1.5 m)
c   pfrac[-]: fraction of easily estractable water (typical 0.6 for Bermuda grass)
c   Hm(m): height of vegetation (from VFSMOD *.igr file, H(cm)/100)
c   iFH(optional): input MET file formating flag where,
C     iFM= 0 (or not present), 8 columns,last two columns are Tmin,Tmax
C     iFM= 1, 7 columns, last column is HRmean
C     iFM= 2, 9 columns, last 3 columns are Tmin,Tmax, Kcmid for a crop other than grass
C     iFM= 3, 8 columns, last 2 columns are HRmin, Kcmid for a crop other than grass
c   REW,soil(isoiltype,1): top soil REW(mm) (see above)
c   TAW(mm): total available water
C-----------------------------------------------------------------
      implicit double precision (a-h, o-z)
      dimension soil(9,3)

      data(soil(1,J),J=1,3)/0.12d0,0.045d0,4.5d0/
      data(soil(2,J),J=1,3)/0.15d0,0.065d0,6.d0/
      data(soil(3,J),J=1,3)/0.23d0,0.11d0,8.d0/
      data(soil(4,J),J=1,3)/0.25d0,0.12d0,9.d0/
      data(soil(5,J),J=1,3)/0.29d0,0.15d0,9.5d0/
      data(soil(6,J),J=1,3)/0.32d0,0.17d0,9.5d0/
      data(soil(7,J),J=1,3)/0.335d0,0.205d0,9.5d0/
      data(soil(8,J),J=1,3)/0.36d0,0.23d0,10.d0/
      data(soil(9,J),J=1,3)/0.36d0,0.22d0,10.d0/

      cKmid=1.d0
      iFM=0
c   iFM =1 or 2: cKmid is read in met file and Kc
c   calculation is bypassed
      read(1,*)isoiltype
      if(isoiltype.eq.-1) then
            backspace(1)
            read(1,*,end=10)isoiltype,OI,FC,WP
         elseif(isoiltype.le.9) then
            FC=soil(isoiltype,1)
            WP=soil(isoiltype,2)
            OI=FC
         else
                write(*,*)'ERROR: wrong soil type selection (-1,9)'
                STOP
      endif
      read(1,*,end=10)Zr,pfrac,Hm
      read(1,*,end=4)iFM
4     return
10    print*,'Error reading input file, please check inputs'
      end


      subroutine theta10(OI,Zr,pfrac,Hm,cKmid,WP,FC,iFM)
C-----------------------------------------------------------------
C Soil moisture calculation, FAO (1998)
C MET file: the last columns can be changed to be read from the
```

```
C   modified EUFOCUS MET files (last 2 columns Tmax,Tmin), and/or
C    provide crop coefficient values (kcmid) for plants other than
C    than grass using the different values of iFM:
C  iFM= 0 (or not present), 8 columns,last two columns are Tmin,Tmax
C  iFM= 1, 7 columns, last column is HRmean
C  iFM= 2, 9 columns, last 3 columns are Tmin,Tmax, Kcmid for a crop other than grass
C  iFM= 3, 8 columns, last 2 columns are HRmin, Kcmid for a crop other than grass
C--------------------------------------------------------------
      implicit double precision (a-h, o-z)
      character*7 datein
      character*100 dum

c-----Initial calculations before the data processing loop
c-----root zone and top layer initial depletion
      Dr=(FC-OI)*Zr*1000.d0
      TAW=(FC-WP)*Zr*1000.d0

c-----Start calculation loop for original .MET file and save file with additional column in
c-----output directory. The scratch file is used to read PRZM date fix format (first column 'A7')
c-----while the other inputs are are read as free format.
      do 10 i=1,10000
        open(25,status='scratch')
        read(2,101,end=30)datein,dum
        write(25,*)dum
        rewind(25)
        SELECT CASE (iFM)
           CASE (1)
              read(25,*)prec,ETo,temp,u2,rad,RHm
           CASE (2)
              read(25,*)prec,ETo,temp,u2,rad,tempmax,tempmin,cKmid
              RHm=RHmin(tempmax,tempmin)
           CASE (3)
              read(25,*)prec,ETo,temp,u2,rad,RHm,cKmid
           CASE DEFAULT
              read(25,*)prec,ETo,temp,u2,rad,tempmax,tempmin
cdebug        write(*,'(i6,8f8.2)')i,prec,ETo,temp,u2,rad,tempmax,tempmin
              RHm=RHmin(tempmax,tempmin)
        END SELECT
        close(25)
c------change units to mm/day (P,ETo) and m/s (u2) from default in MET file ------
        precmm=prec*10.d0
        ETomm=ETo*10.d0
        u2m=u2/100.d0
                       if(u2m.lt.0.d0)u2m=0.d0
c-----Calculate adjusted crop coefficient (cKb) based on daily wind and relative temperature
        cKbadj=(0.04d0*(u2m-2.d0)-0.004d0*(RHm-45.d0))*(Hm/3.d0)**0.3d0
        cKb=cKmid+cKbadj
        ETc=cKb*ETomm
c-----Calculate root zone layer depletion (Dr) from the daily soil water balance
        DP= precmm-ETc-Dr
        if(DP.lt.0.d0) DP=0.d0
        Dr=Dr-precmm+ETc+DP
        if(Dr.lt.0.d0) Dr=0.d0
        if(Dr.gt.TAW)  Dr=TAW
c-----Calculate soil water stress coefficient (cKs)
        peff=pfrac+0.04d0*(5.d0-ETc)
        RAW=TAW*peff
        if(Dr.gt.RAW)then
            cKs=(TAW-Dr)/(TAW-RAW)
          else
            cKs=1.d0
        endif
c-----Calculate the actual ET (ETa) and calculate the topsoil moisture
        ETa=cKb*cKs*ETomm
c-----Calculate the soil moisture (depth Zr)
        thetamm=1000.d0*FC*Zr-Dr
        theta=thetamm/(Zr*1000.d0)
c-----Write the new theta10 and ETa columns to the output/*.met file
cdebug        write(*,200)i,precmm,ETomm,u2m,RHm,cKb,ETc,pfrac,peff,
cdebug     &     RAW,TAW,Dr,DP,cKs,ETa,theta
        if(iFM.eq.1.or.iFM.eq.3) then
```

```
c           write(4,102)datein,prec,ETo,temp,u2,rad,RHm,theta
           write(4,102)datein,prec,ETo,temp,u2,rad,RHm,theta,ETa/10.d0
         else
c           write(4,100)datein,prec,ETo,temp,u2,rad,tempmax,tempmin,
c     &       theta
           write(4,100)datein,prec,ETo,temp,u2,rad,tempmax,tempmin,
     &       theta,ETa/10.d0
        endif
10    continue

100   format(a7,2f10.2,f10.1,f10.0,f10.1,2f10.2,f10.3,f10.3)
101   format(a7,a100)
102   format(a7,2f10.2,f10.1,f10.0,f10.1,f10.2,f10.3,f10.3)
cdebug 200   format(i6,20f10.3)

30    return
      end


      function RHmin(tempmax,tempmin)
c-----------------------------------------------------------------
c--- Estimate missing RHmin based on assumption Tmin<>Tdew
c-----------------------------------------------------------------
      implicit double precision (a-h, o-z)

      a1= 17.625d0
      b1= 243.04d0
      c1= 0.61121d0
      ea= c1*dexp(a1*tempmin/(tempmin+b1))
      es= c1*dexp(a1*tempmax/(tempmax+b1))
      RHmin=100.d00*ea/es
      if(RHmin.gt.100.d0) RHmin=100.d0

      return
      end


      subroutine results(isoiltype,OI,FC,WP,Zr,pfrac,Hm,TAW,cKmid,iFM)
C-----------------------------------------------------------------
C      Output summary of hydrology results nicely
C-----------------------------------------------------------------
      implicit double precision (a-h, o-z)
      character*13 stype(9)
      data stype/'Sand','LoamySand','SandyLoam','Loam','SiltyLoam',
     1 'Silt','SiltyClayLoam','SiltyClay','Clay'/

      TAW=(FC-WP)*Zr*1000.d0
      write(3,*)' '
      write(3,*)'TOP SOIL MOISTURE CALCULATION FAO (1998) METHOD'
      write(3,*)' '
      write(3,*)'INPUTS'
      write(3,*)'------'
      if(isoiltype.eq.-1) then
                       write(3,200)'User'
                else
                       write(3,200)stype(isoiltype)
      endif
      write(3,250)FC
      write(3,300)WP
      write(3,325)OI
      write(3,450)Zr
      write(3,500)pfrac
      write(3,600)TAW
                  if (iFM.eq.2.or.iFM.eq.3) then
                       write(3,655)
                   else
                       write(3,650)cKmid
      endif
      write(3,700)Hm
      SELECT CASE (iFM)
         CASE (1)
```

```
        write(3,800)iFM,'last column RHmean            '
     CASE (2)
        write(3,800)iFM,'last 3 columns Tmax,Tmin,cKmid'
     CASE (3)
        write(3,800)iFM,'last 2 columns RHmean,cKmid   '
     CASE DEFAULT
        write(3,800)iFM,'last 2 columns Tmax,Tmin      '
  END SELECT
  write(3,*)' '

200   format('Soil type',34x,'=',a13)
250   format('Top soil field capacity, FC(m3/m3)',14x,'=',f9.3)
300   format('Top soil wilting point, WP(m3/m3)',15x,'=',f9.3)
325   format('Top soil initial water content, OI(m3/m3)',7x,'=',f9.3)
450   format('Maximum grass root zone depth, Zr(m)',12x,'=',f8.2)
500   format('Fraction of easily extractable water,pfrac',6x,'=',f8.2)
600   format('Total available water, TAW(mm)',18x,'=',f8.2)
650   format('Mid season crop coeff., Kcmid',19x,'='f8.2)
655   format('Mid season crop coeff., Kcmid',19x,
     & '=    variable (.MET file)')
700   format('Vegetation height, H(m)',25x,'=',f8.2)
800   format('Input format option for MET file, iFM =',i2,7x,'=',a34)

      return
      end
```