VSIM - Vineyard Soil Irrigation Model – release 3/1/06 - User Guide

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Introduction

VSIM is a simple water balance model embedded in an Excel spreadsheet (see Figure on last page) that simulates the daily and seasonal water balance for a vineyard (block) given information about the vineyard climate, soils, and leaf area index (LAI). LAI is the leaf area per unit ground area and is a measure of the leaf transpiration surface area. VSIM is a simplification of previous ecosystem water balance models (e.g. Running and Coughlan, 1988) that takes advantage of the weather and evaporation data available from the CA Dept. of Water Resources California Irrigation Management Information System (CIMIS) or the US Bureau of Reclamation's Agrimet System. The user can manipulate the climate, LAI, soil water parameters, crop coefficient (Kc), and a cover crop to examine the effects that these variables have on soil moisture, irrigation requirement, and vine water stress. Daily water gains and losses are used to calculate a daily water balance. Daily water gains are rainfall and irrigation, and water losses are evapotranspiration (ET) for the vine and cover crop (if desired) and runoff. Each day, the difference between soil water gains and losses are added (or subtracted) from soil moisture (SM) to estimate soil moisture on a daily basis. Crop ET (ETc) is calculated from the FAO crop model where ETc = ETo * Kc, and ETo = daily evaporation for a well-watered, grass surface, and Kc = crop coefficient (CIMIS, 2002). Kc is calculated as a linear function of LAI and stem/soil water potential (if desired). Canopy LAI is "grown" from budbreak in VSIM based on the growing degree day (GDD) sum and a calculated relationship between LAI growth and GDD. The user needs to calculate and enter the GDD sum (Tbase = 0C) from Jan. 1 to budbreak, and the GDD sum (Tbase = 10C) from budbreak to peak seasonal LAI.

The simulation is contained on the "Daily Water Balance" worksheet. The delivered excel file also contains sheets that further describe the input parameters, contain daily weather data from California (CIMIS) and Oregon (Agrimet), and sheets that assist with irrigation conversion.

Daily Weather:

Average daily temperature (Tavg, C), Potential ET (ETo, mm), and daily rainfall (Precip, mm), represent the weather inputs and are downloaded from the California Irrigation Management Information System (CIMIS, 2002; http://wwwcimis.water.ca.gov) web site to drive the model for any given period of time (note that although this service is free, you need to register with CIMIS in order to obtain a login name and password to access CIMIS weather data). For the Northwest US, daily weather data needed to run VSIM (Tavg, ETo, and rainfall) can be downloaded from the US Bureau of Reclamation Agrimet web site (http://www.usbr.gov/pn/agrimet). CIMIS data (in metric format) can be downloaded into a CSV format (w/ headers) file that can be imported directly into MS Excel. Agrimet data (column headings and data only) must be copied from the web page into a text file (.txt format) using a text file editor (e.g. Notepad). Save the text file, and then import it into Excel.

Note that CIMIS ETo estimates are derived for a well-watered lawn surface type, while Agrimet ETo estimates are derived for an alfalfa crop type. Therefore, Agrimet ETo estimates are slightly higher than CIMIS ETo estimates during the growing season. To reduce Agrimet ETo estimates to match CIMIS ETo estimates, you can use the following regression equation (R2 = 0.96):

CIMIS_ETo = 0.001 + (0.988*Agrimet_ETo) + (-0.586*(Agri_ETo* Agri_ETo)),

where ETo is in inches (not that you will need to convert ETo to mm for input into VSIM). The regression equation was developed using daily ETo for locations on the California-Oregon border where CIMIS and Agrimet stations overlap. This equation is included in the Agrimet-format climate worksheets to help you scale the ETo data and convert everything to metric units.

If your vineyard block is located on sloped terrain, you will need to correct your Agrimet or CIMIS ETo data for radiation differences due to slope and aspect. You can use the 'SlopeCorrection' worksheet to do this. You will need to know the latitude, slope, and aspect of your vineyard block because this effects radiation loading and ETo. South-facing slopes have higher radiation loads, and hence higher ETo in comparison to flat locations typical of climate stations. North-facing slopes have a reduced radiation load and ETo.

Tavg is used to calculate Growing Degree Days (GDD) which are used to calculate the seasonal trajectory of LAI growth. Rainfall is supplied directly to the soil moisture storage compartment (SM), and ETo is used to calculate evapotranspiration of a cover crop (if desired) and the vine. The weather data occupy a separate sheet within the excel file and must have the same column/row format as the example climate files. To add a new weather file, you can either copy over the existing weather file, or insert a new worksheet and copy the weather data to the new worksheet and give the worksheet a defining name (e.g. Oak2001 for Oakville 2001 weather). To change weather inputs to VSIM, you change the entry in cell B30 to the name of the worksheet containing the new weather data. Remember that your weather data should ultimately be in metric units (C, mm/day) and located in columns B-D of your climate worksheet.

Daily Actual Irrigation inputs:
Irrigation (mm) can also be input if these data are available (‘Simulate irrigation’ = 0), otherwise the model will simulate the daily irrigation requirement (‘Simulate irrigation’ = 1). If you choose to simulate irrigation, please set the ‘optimal midday stem water potential’ parameter to your desired value (-7 to -9 bars is a good average). Irrigation data may need to be converted by the user into units of mm (depth) given the vine and row spacing (if irrigation data consists of gallons/vine, etc.). For convenience, an “Irrig converter” worksheet is included to help in converting irrigation units from gallons per vine to mm depth.

Soil Moisture Characteristic:
You will need to know the soil texture and depth in order to calculate the maximum soil water-holding capacity (SWHC), and the soil moisture (SM) vs. water potential (WP) characteristic curve. To calculate maximum SWHC, you need to know, or have an estimate of, the gravel fraction (0-1), soil or rooting depth (m, whichever is shallower), and the %sand and %clay (or USDA soil texture class). Given %sand and %clay, you can estimate the fractional water storage at field capacity (WSFC) from the literature. The maximum SWHC = gravel fraction * WSFC * depth. Initial soil moisture should also be known, or can be guesstimated. If you begin your VSIM simulation on January 1, it is probably reasonable to assume (for Napa) that the soil is saturated (i.e. initial soil moisture = maximum SWHC). The %sand and %clay are then used to calculate the soil water model A and B coefficients for the soil water content vs. water potential characteristic curve (Saxton et al., 1986). We assume that soil WP = pre-dawn leaf WP. The minimum soil moisture is used as a lower bound on soil moisture and is calculated as the amount of water in the soil at wilting point (-15 bars). Field capacity and wilting point can be estimated using the interactive USDA soil texture triangle hydraulic properties calculator at http://www.bsyse.wsu.edu/saxton/soilwater/.

Leaf area index (LAI):
LAI is estimated from the growing degree day (GDD) sum based on a predetermined relationship between LAI and GDD for a particular year and block (e.g. Williams, 2001). LAI is set to 0 before budbreak and after the "Date of Leaf Drop". LAI growth starts at budbreak. Date of budbreak is determined from a GDD sum – in this case, GDD’s are summed starting from Jan. 1, using a base temperature of 0^oC (daily GDD = Tavg – 0, for days when Tavg > 0). To calculate the GDD sum for budbreak (Tbase = 0C), you will need to know the average date of budbreak for your vineyard. Then you calculate the GDD sum (Tbase = 0C) from January 1 until the date of budbreak for each of the last several years, and then calculate the average GDD sum for date of budbreak. This is the value you enter into VSIM. For vine varieties in the warmer Napa-Tokalon region, 865 GDDs are needed for budbreak to occur, while varieties in the cooler Napa-Carneros region need only 709 GDDs.

Once budbreak has occurred, LAI growth begins using a GDD sum and a base temperature of $10\,^oC$. VSIM uses a sigmoidal growth curve (typical for agricultural crop development) to relate the relative peak seasonal LAI (0-1; specified) to the maximum GDD sum (Tbase = 10C) on the approximate date when peak LAI is achieved. In order for VSIM to “grow” the canopy, the user needs to input the peak seasonal LAI (MaxLAI) and the GDD sum (Tbase =10C) from budbreak to the approximate date on which peak LAI is reached (GDD_MaxLAI). GDD_MaxLAI is calculated for your area in the same way that the GDD sum for budbreak is calculated. Finally, VSIM "grows" the canopy based on the daily the GDD sum (Tbase =10C) from budbreak for the day in which LAI needs to be estimated (GDD10_sum), where:

LAI = 1.0066-1.0118*EXP(-5.0278*(GDD10_sum/GDD_MaxLAI)^1.9331))*MaxLAI.

The sigmoidal growth curve relationship between LAI and GDD sum was determined using several Napa Valley blocks where we had LAI measurements on specific dates – we then used the daily temperature data for those years to calculate the GDD sum from budbreak on each day that LAI was known. The LAI data should be normalized from 0-1 based on the peak LAI. A curve is then fit to this relationship, and this is used to calculate the fractional LAI from the GDD sum. This fractional LAI value (0-1) is multiplied by the peak LAI of the block to estimate daily LAI. Daily Kc is based on an estimate of canopy radiation interception and is calculated from LAI using Beer's Law and a light extinction coefficient (greater LAI = greater light interception = greater Kc). A scalar for Kc is also calculated as a function of pre-dawn LWP, and this scalar can be used to reduce Kc when LWP is low (if desired - this can be set using the 0-1 switch "Alter Kc by LWP?"). LAI increases following a sigmoidal growth pattern from the start of the growing season according to the GDD sum until it reaches the peak LAI value.

Cover Crop:
A cover crop can also be grown if desired to reduce soil moisture early in the season. Parameters describing the last day the cover crop is active (date) and cover crop Kc (Kcc) must be entered in the Parameter Worksheet. The cover crop Kc is estimated as the percent ground cover of the cover crop. The cover crop is assumed to be on the ground and actively transpiring from the start of the simulation until either the soil moisture is less than 60% of field capacity, or until the last date that the user specifies that the cover crop is active. Kcc is linearly adjusted in relation to soil moisture, and is at a maximum when soil moisture is at field capacity, and goes to 0 when soil moisture reaches 60% of field capacity. The ET of the cover crop, ETcc = Kcc * ETo. If no cover crop is desired, set Kcc = 0.

Simulated Irrigation:
Irrigation can be based on actual irrigation data, or it can be simulated, by setting the 0-1 parameter switch for "simulate irrigation?". Actual irrigation is added directly to soil moisture. Simulated irrigation, if desired, replaces actual irrigation, and is calculated by inverting the soil moisture vs. water potential characteristic curve and solving for the "optimal soil moisture" given an "optimal stem water potential (SWP)". The optimal or target SWP must be supplied by the user. Irrigation is simulated on any day when the soil moisture store falls below the SWP threshold. The water required to increase soil moisture to the "optimal soil moisture" is added to the soil moisture store as simulated irrigation (typically ~10mm per irrigation event). Simulated irrigation is useful if you want to look at the effects of climate, LAI (vine spacing), and/or soil texture/depth on total irrigation requirement. Alternatively, actual irrigation data are useful to follow the seasonal course in soil moisture or leaf water potential. If actual irrigation data are available, they need to be in units of mm depth. See the "Irrigation" worksheet to convert daily irrigation values from gallons/vine to mm depth.

Water Balance:
The water balance is calculated by accounting for all gains and losses of water. Gains or inputs (considered positive values) are daily rainfall and irrigation (actual or simulated). Losses or outputs (considered negative values) are evapotranspiration of the cover crop (ETcc) and vine (ETc), and runoff. ETc = ETo * Final Kc. The vine Kc is scaled directly from vine LAI based on Beer's Law, using an extinction coefficient of 0.6 (Campbell and Norman, 1997). Vine Kc can also be scaled by the soil/stem water potential, if desired (see Stem Water Potential, below), where Kc decreases linearly with soil/stem water potential. Daily runoff is calculated when water inputs + soil moisture exceed the maximum water-holding capacity of the soil. To represent temporally saturated soil moisture conditions, VSIM allows up to 25% of excess moisture to runoff each day. Inputs and outputs of water are added and subtracted from the soil moisture store each day to keep a running total of soil water content.

Stem Water Potential (SWP):

The stem water potential is calculated using the soil water content vs. water potential characteristic curve (described above based on Saxton et al., 1986), and assuming that the stem water potential is equal to soil water potential. Stem water potential is used as a measure of vine water stress, and can also be used to scale Kc for the effects of plant water status on stomatal conductance and transpiration (after Allen et al., 1998). The Final Kc can be scaled by stem water potential, if desired, so that Kc decreases as stem water potential decreases (see the "Leaf Area Index" section above for details). The scalar for Kc is calculated as a function of SWP, and this scalar can be used to reduce Kc when SWP is low (if desired - this can be set using the 0-1 switch "Alter Kc by LWP?").

Running VSIM:
Prior to running VSIM, the user needs to have downloaded the appropriate weather data for the site and year of interest, and entered this data into a VSIM worksheet in the appropriate format. The user also needs to have determined and entered a value for each input parameter in **bold** on the 'Daily Water Balance" sheet. Take care in preparing the weather data and in determining the parameter values as these control the VSIM simulations. Each water balance variable is calculated on a daily basis by the Water Balance Worksheet. These values can be graphed, and the seasonal sums and/or averages can be compared. Two figures have already been set up. The first figure (left-hand side) graphs the daily values of all the important water balance variables over the season; Rainfall (Precip), Cover crop ET (ETcc), Vine ET (ETc), Irrigation (simulated or actual), Runoff, and Soil Moisture (SM). Rainfall, runoff, and soil moisture are graphed on the secondary (right-side) y-axis. The second figure graphs the daily LAI, Cover crop Kc, Vine Kc, and stem water potential (SWP). You can change the values of the input parameters to examine their effect on water balance. You can examine the effects of different climates by inserting other climate data, or examine the effects of different irrigation strategies by altering inputs in the "Actual Irrigation" column. The parameter description sheet and the water balance worksheet (except for the parameter values) are read-only (you can unprotect these worksheets without a password). Specific equations and model logic can be seen by selecting the appropriate column or cell in the Water Balance Worksheet.

VSIM assumes that the user has access to and a basic working knowledge of Microsoft Excel 2000 or later. VSIM assumes a homogeneous canopy, rather than a true agricultural canopy with vegetation in rows and open spaces between rows. Irrigation inputs are calculated in a depth format, and do not consider the spatial heterogeneity in soil moisture that comes with canopy development and irrigation. Therefore, it becomes more difficult to use and translate VSIM irrigation estimates as vineyard row/vine spacing increases. **We do not recommend the use of VSIM to derive direct irrigation estimates for your vineyard.** Rather, VSIM should be considered as one of many tools in helping the vineyard manager to understand vineyard water balance. We recommend that you combine VSIM with field-based measurements (soil moisture, vine water potential) and your knowledge and experience in the vineyard, to design an irrigation scheme that works for your particular vineyard in any particular year. We are constantly working to improve and test the VSIM model, so check back occasionally for improved versions.

Citations

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VSIM Daily Water Balance Model

2 plant layers (vine, cover crop) & 1 soil layer