Groundwater

SWIB—An Online Model to Estimate Daily Crop Water Stress, Irrigation Needs, and Soil Water Budget

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Introduction

The amount of water stored in the soil is the resultant of the interdependence of soil, climate, and biota, with ecosystems that are under significant human impact being subjected to additional controlling factors. For example, for agroecosystems, the irrigation regime can play a significant role on the amount of water stored in the soil during the growing season. Hence, knowledge of the state and dynamics of soil water storage is a key step for advancing our understanding relative to the hydrological cycle, ecosystem health or agroecosystem productivity. Soil moisture is a key element for applications related for example to the impact of severe weather (e.g., droughts) on soil water availability; the impact of water stress (water deficit and excess) on natural vegetation and agricultural crops; the impact of climate change on soil water storage and vegetation; movement of water and solutes (e.g., contaminants) through soil; irrigation requirements for agricultural production; or relationship between irrigation water supply and aquifer storage.

SWIB (Soil Water Stress, Irrigation Requirement and Water Balance) model is a unique, free online dynamic model (https://swib.hydrotools.tech) which allows for daily estimation of (1) crop water stress (either as water deficit or water excess) and precipitation deficit; (2) supplemental irrigation requirements and the impact of irrigation of aquifer storage; and (3) soil water budget terms. Routines for estimation of these components have been integrated in the past in software packages that were typically developed for specific applications; however, these models can have complex input data requirements and require considerable expertise for proper parameterization, calibration, and validation (Ascough et al. 2008; Jones et al. 2016). There are currently no online tools available for calculation of soil water deficit/excess or irrigation requirement using a daily timestep and no online tools for calculation of soil water budget or the impacts of irrigation on aquifer storage have been identified.

The model can be used for a broad range of applications such as studies aimed at understanding the significance of soil properties on the dynamics and magnitude of crop water stress, impact of irrigation triggering thresholds and scheduling on soil water content (SWC), effect of irrigation losses on SWC and on irrigation water supply requirements, influence of groundwater-sourced irrigation on aquifer storage, evaluation of various soil water budget components (e.g., evaporative losses, soil moisture losses and gains, soil drainage, infiltration, and surface runoff). Broader applications of SWIB include generation of critical data for external models that allow for uploading of user-provided timeseries; or use in educational settings for example to demonstrate the significance of various of concepts related to crop water stress (i.e., water deficit or excess), irrigation practices and soil water balance.

SWIB Development

SWIB is part of the Hydrology Tool Set suite (HTS; https://portal.hydrotools.tech), which also includes SepHydro (11 algorithms for stream hydrograph or baseflow separation; Danielescu et al. 2018); ETCalc (8 methods for estimation of evapotranspiration; Danielescu 2022); and SNOSWAB (innovative model for estimation of soil water content, snow-related processes and soil water budget). Future HTS plans

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include development of additional tools, such as tools for snowfall estimation based on total precipitation and air temperature, and groundwater recharge estimation based on changes in water table elevations and substrate properties. SWIB was developed through a collaborative research effort between Canadian Rivers Institute (CRI), Agriculture and Agri-Food Canada (AAFC) and Environment and Climate Change Canada (ECCC). SWIB has been initially developed as part of a research effort aimed at evaluating the effects of agricultural production practices on the quantity and quality of groundwater and surface water in Atlantic Canada.

The development of SWIB, as well as of the other tools included in HTS, has been guided by the effort of the Canadian federal government to encourage easier and open access to science (OCSAC 2020). Hence SWIB has been developed using the following key principles:

- Freely available (i.e., no cost and no user registration required);
- User-friendly interface, with streamlined and easy to follow procedures;
- Minimal input data requirements and input data generally available to the public;
- High degree of flexibility (e.g., choice of methods; adjustable parameters/coefficients).

SWIB was programmed in PHP 7.4, has cross browser compatibility, unrestricted public access and does not require user registration or downloading of software. Since its launch in March 2022 SWIB was accessed by ~1100 unique visitors, with users accessing the model from many regions of the globe.

SWIB Interface

A screen capture of the SWIB layout is presented in Figure 1. The top row provides access to the SWIB modules and includes a link for accessing HTS. The second top row of the SWIB interface is dedicated to the menus of each module (i.e., Module Menu). The Working Window covers the central part of the screen and includes elements specific to each Module Menu.

SWIB Workflow

SWIB has been designed with ease of access and use in mind as shown in the workflow diagram (Figure 2). Hence, the end result of the analysis can be achieved by completing four intuitive steps as follows: (1) load input data; (2) conduct water stress analysis; (3) conduct irrigation analysis; and (4) conduct water balance analysis.

SWIB Modules

A brief description of the SWIB calculation modules is included below. A full description of the model, including conceptual model, methodology, and data requirements, together with a User Guide is available on the model homepage. An application of the SWIB model for estimation of the crop water stress and supplemental irrigation requirements is presented in Danielescu et al. (2022), a study conducted using 10 years of daily data collected from a field under intensive potato production in Prince Edward Island, Canada.

Input Data Module

SWIB can be used with the test daily dataset, supplied for allowing users to familiarize with the model, or with a user provided daily dataset. The input data file has a spreadsheet format with one column for calendar date, three columns for required input data (TP—total precipitation, SWC—soil water content, ET—actual evapotranspiration), one column for groundwater recharge (RCH; optional) and up to five columns for optional

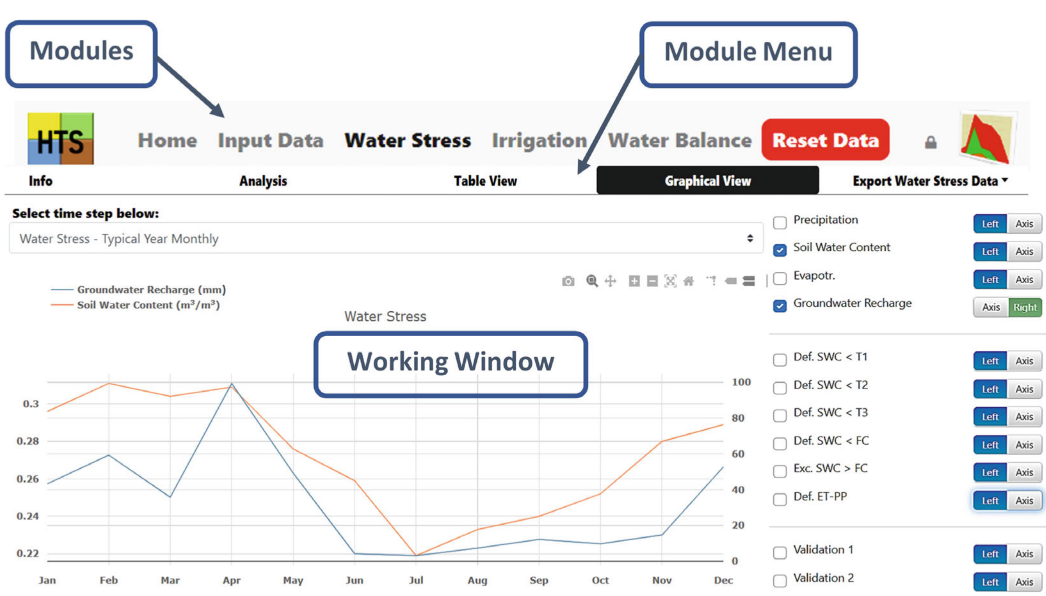

Figure 1. SWIB interface (e.g., from Water Stress Graphical View menu).

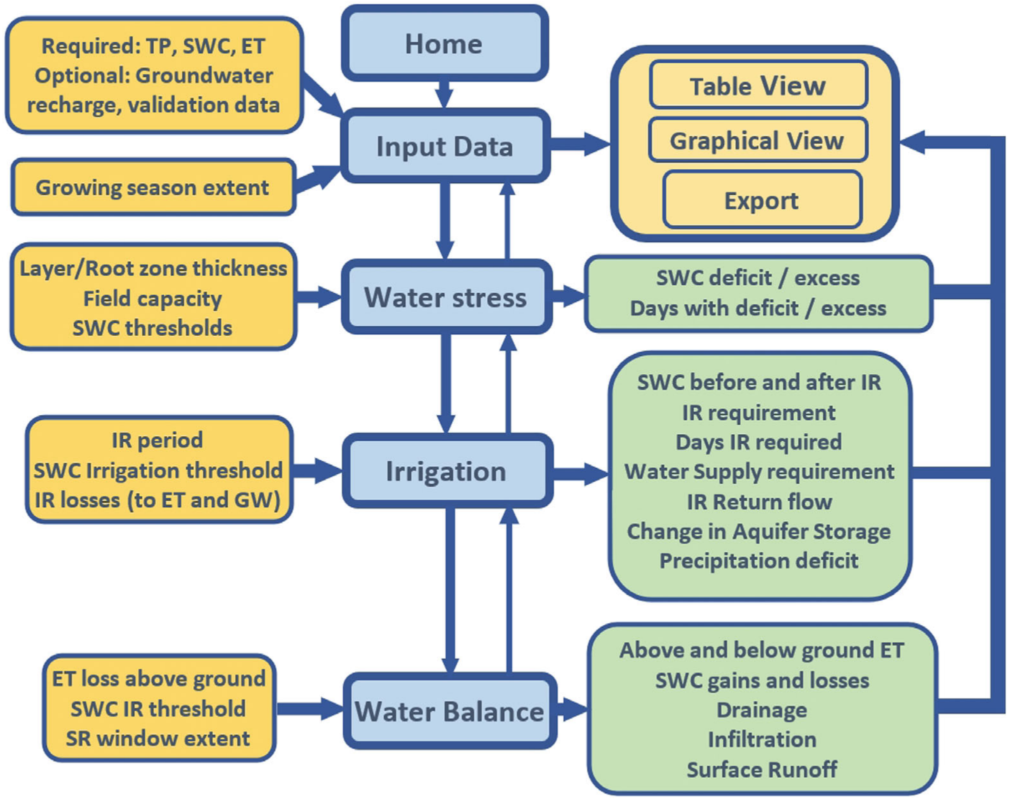

Figure 2. SWIB workflow. ET, daily crop/actual evapotranspiration; GW, groundwater; IR, irrigation; SR, surface runoff; SWC, soil water content; TP, total precipitation.

user-provided validation data (VD1 to VD5). The required input data can be obtained via in situ measurements, from local monitoring stations, or from public databases. ET can be estimated with ETCalc (https://etcalc.hydrotools.tech). The required SWC daily timeseries input can be estimated using SNOSWAB (https://snoswab.hydrotools.tech). The validation data timeseries are not restricted to certain parameters and can include for example daily timeseries of drainage, evapotranspiration, soil moisture, soil temperature, water table elevations, and so on.

Water Stress Module

The Water Stress module becomes available once the upload of the input data is completed. This module allows for calculation of daily water stress, either as water deficit or water stress. To allow for the calculations to proceed, the user must specify the soil (or root) layer thickness, field capacity (FC) and water stress thresholds. The extent of the water deficit is calculated as the number of days for which the soil is below the user specified SWC thresholds, while the extent of the water excess is calculated as the number of days for which SWC is higher than the soil field capacity (FC). For each day, the amount of water deficit or excess corresponding to each threshold is calculated as the difference between each threshold and SWC, and as the difference between FC and SWC, respectively. In addition to the SWC-based water stress calculations, SWIB also calculates the precipitation deficit. The precipitation deficit, also known as water deficiency, is calculated as the difference between ET and TP for the days when ET is higher than TP, with a positive value indicating the presence of precipitation deficit. Precipitation deficit provides an alternative method for assessing crop irrigation requirements, however the calculation of water deficit using the SWC method is preferred since precipitation deficit does not account for either the actual soil water content or soil properties.

Irrigation Module

The Irrigation module becomes available once the calculations for the Water Stress module are completed. This module allows for calculation of daily crop supplemental irrigation requirement, irrigation water supply requirement (i.e., by accounting for irrigation losses) and the change in aquifer storage due to irrigation if irrigation is sourced from groundwater. To allow for the calculations to proceed the user must specify the extent of the irrigation season, the SWC threshold for triggering irrigation as well as the portion of irrigation water lost to ET or to groundwater (i.e., return flow). SWIB calculates the number of days when irrigation is required, the crop irrigation requirement and by considering the losses to ET and return flow, the irrigation water supply requirement. The crop irrigation requirement (IR) is defined as the amount of water required to elevate SWC to the user-specified irrigation threshold (THR) on days with SWC lower than the THR. Groundwater recharge (RCH) is used in combination with the irrigation water supply requirement for calculating the net change in aquifer storage. In the absence of RCH data, SWIB will assume that the net change in aquifer storage is equal to the irrigation water supply requirement.

Water Balance Module

The Water Balance module becomes available once the calculations for the Irrigation module are completed. This module allows for daily calculation of various water budget components in the absence of supplemental irrigation. To allow for the calculations to proceed the user must specify the portion of ET occurring above soil and the width of the window used for calculation of surface runoff (SR). The calculated water balance components include above and below soil ET fractions (ETAS and ETFS), SR, soil drainage (DR), change in soil water storage (ΔS) and the unaccounted losses or gains (OTH). The model's water balance error (OTH%) can be estimated as the proportion of unaccounted losses or gains relative to TP and the water balance estimates should be considered reasonable if this value is less than 10%. The presence of unaccounted water losses or gains can be related to measurement and estimation errors in input data, assumptions of the model and rounding errors. For the days when Net Gains in SWC are present (i.e., positive difference in measured SWC between two consecutive), SWIB also calculates infiltration (INF) and surface runoff, with infiltration being the sum of the daily Net Gain and ETFS and SR being the difference between TP and INF. Infiltration and drainage rates can simply be calculated by dividing SR or DR, respectively to the extent of the averaging interval.

Data Inspection, Visualization, and Export

Inspection and visualization of both input and output data can be conducted via the various options available under the Table View and Graphical View menu entries available for the SWIB modules. The data are available as daily timeseries as well as monthly, growing season and annual periods. In addition, values for the "representative" (or average) year, based on the daily values for each parameter in each of the years available in the input data are calculated and averaged over the same intervals. The various options available under the Table View and Graphical View allow for customizing the displayed data using selected time frames, averaging intervals, units and set of parameters.

The Export Data menu entry offers several options for exporting the timeseries using various time steps and intervals. The Export Data Tab also provides options for exporting basic statistics (i.e., average, minimum, maximum, standard deviation) and metadata (i.e., parameters and coefficients used by the user in the respective module). The plots created with SWIB can be exported as images using the plot controls available in Graphical View.

Limitations

SWIB includes several data quality check routines (e.g., missing data, out of range values); however, users are advised to conduct a thorough data quality check before uploading data into the model. Daily surface runoff calculations could be subject to errors due to the delay between the time of precipitation and the actual response in soil moisture (1 to 2 days) as well as due to the possible presence of snow related processes (e.g., snowfall, snowpack, snowmelt) during the cold periods of the year.

Conclusions

Here, we introduced SWIB, a unique, free online dynamic model (https://swib.hydrotools.tech) for estimation of daily crop water stress (expressed either as deficit or excess); precipitation deficit (water deficiency); crop irrigation and irrigation water supply requirements; the impact of irrigation on soil water content and on aquifer storage; and soil water budget (i.e., surface runoff, soil evapotranspiration, soil drainage, soil water storage and infiltration). Input data for the model includes daily soil water content, precipitation and evapotranspiration, and a minimal set of soil properties and model coefficients. SWIB is the first online model that allows for analysis of daily SWC time series for estimating the above processes. Through an easy access, streamlined interface SWIB provides options for adjusting the coefficients used by each of its modules (i.e., Input Data, Water Stress, Irrigation, Water Balance) and for inspection, visualization and export of input, output and metadata. The model is freely available, and its applicability is not limited to specific climate zones or geographic areas. Future SWIB development plans include addition of multiple irrigation periods and integration of functionality for importing metadata.

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