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# How sensitive is a vineyard crop model to the uncertainty of its runoff module?

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ABSTRACT

Many crop models use the NRCS Curve Number method to estimate runoff, but the simplified assumptions of this method are rarely considered in model uncertainty assessments. The associated uncertainty may be high for cropping systems with a significant part of bare soil like vineyards, specifically under a Mediterranean climate. In this work, we evaluate for a vineyard crop model the structure uncertainty coming from its uncertain runoff module. We introduce a new method based on additional knowledge about the runoff process and on a mathematical property of the model structure. Situations characterized in terms of soil water content and mean runoff conditions are studied for two applications of the vineyard model and guidelines for model users are derived. This work shows that uncertainty quantification can benefit from the knowledge of mathematical properties of a model and provide clear guidelines to model users.



## 1. Introduction

The use of simulation models in environmental applications is affected by various sources of uncertainty (Refsgaard et al., 2007; Matott et al., 2009). Walker et al. (2003) distinguished four of them: context uncertainty, model structure uncertainty, input and parameters uncertainty and technical uncertainty. A major challenge in modelling is the model structure uncertainty, because it questions the way the system and its drivers have been formalized and because this uncertainty can be large even under the ideal case when the other sources do not cause any uncertainty in the model output. Even if all uncertainty sources can play a major role in the total output uncertainty, estimating the structure uncertainty of a model is always a central and challenging issue when developing and testing a model (Refsgaard et al., 2006).

In the present work we address the issue of the structure uncertainty of a water stress crop model widely applied to vineyards (Gaudin and Gary, 2012; Pellegrino et al., 2006; Celette et al., 2010; Ripoche et al., 2011; Roux et al., 2014a) and concentrate on the uncertainty associated with the runoff module used in this model: The National Resources Conservation Services's (NRCS) Curve Number (NRCS, 2004). This module is also used in a lot of crop models: The review by Ahuja et al. (2014) mentions APSIM (Keating et al., 2003), AquaCrop (Steduto et al., 2009), CropSyst (Stockle et al., 2003), DSSAT (Jones et al., 2003) and EPIC (Williams et al., 1989). Even if other uncertainty sources may dominate the model behaviour depending on how the model is used, uncertainty coming from the NRCS runoff module is identified as critical in our modelling context because i) runoff is an important flux in crops with a significant part of bare soil like vineyards (Celette et al., 2008), ii) the model is often used under a Mediterranean climate for which rainfall events are frequently stormy (Gaudin et al., 2010), iii) the runoff module suffers from well known limitations such as the absence of rainfall intensity as an explanatory variable and the determination of the Antecedent Runoff Conditions based on precipitations accumulation (Young and Carleton, 2006; Hjelmfelt, 1991).

The objective of this work is to provide guidelines regarding the situations where the uncertainty in the model output is weakly or strongly affected by the uncertainty of the NRCS runoff module. Such information would be precious for users but is rarely provided with crop models: It indeed requires analysing the uncertainty response when model inputs vary, which is more difficult than computing the bias and variance of the uncertainty distribution.

There are classically two ways for quantifying the structure uncertainty of a model (Refsgaard et al., 2006; Matott et al., 2009; Wallach et al., 2017). The first one involves experimental data and consists in adjusting a dedicated error model, while taking into account all sources of uncertainty. Such approaches assume that

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the associated error estimates are valid for new predictions. Error estimates have been computed on the vineyard model in previous studies (Celette et al., 2010) and (Roux et al., 2014a), but they were limited to averaged levels of total error and do not allow errors to be analysed as a function of model inputs. The second method is based on multi-model comparisons. In our context this approach could consist in using a more mechanistic model instead of the NRCS runoff module and coupling it with the vineyard water stress model. Assuming a negligible error in the model parameters, the discrepancy between the two models and its response to the model inputs could then provide properties of the NRCS model structure uncertainty. Here we propose a more easy-to-implement approach that does not require using and coupling an additional runoff model. The method relies on additional knowledge about the runoff process and on a mathematical property of the model structure.

The paper is organized as follows: We first briefly describe the NRCS Curve Number method and the vineyard water stress model in section 2.1. The uncertainty estimation method is derived in section 2.2. Two contrasted cases of model application of the method are introduced in section 2.3 and numerical results on uncertainty exploration are presented in section 3.

## 2. Material and methods

### 2.1. NRCS curve number module and vineyard crop model

#### 2.1.1. NRCS curve number module

In this section we describe the main aspects of the NRCS Curve Number method when applied to daily time-step crop models, as proposed in NRCS (2004). Let $Q^t$ denote the daily runoff associated to a daily rainfall event $P^t$. In the NRCS model, $Q^t$ is estimated by $\widehat{Q}^t$ which is deduced from $P^t$ and from a retention parameter $S$:

$$\widehat{Q}^t(S, P^t) = \begin{cases} 0 & \text{if } P^t < 0.2S \\ \dfrac{(P^t - 0.2S)^2}{P^t + 0.8S} & \text{if } P^t \geq 0.2 \end{cases} \quad (1)$$

The retention parameter $S$ is linked to the so-called Curve Number ($CN$) thanks to the scaling formula $CN = \frac{1000}{10+S/25.4}$.

For a given runoff event $Q^t$, the optimal retention parameter $S^t$ (and thus the associated optimal curve number $CN^t$) is known to vary strongly from a rainfall event to another. Some practical recipe are given in the NRCS document. A classical one consists in defining three curves $\widehat{Q}^t(CN, P^t)$ associated to three values $(CN_I, CN_{II}, CN_{III})$ which represent the runoff response to dry, medium and wet antecedent runoff conditions. For each rainfall event $P^t$, one of these curves is used to compute the runoff amount $\widehat{Q}^t$ from the rainfall $P^t$. A common way to choose between the three classes of antecedent runoff conditions is based on the rainfall accumulated over the five previous days (NRCS, 2004). When coupled with a crop model, the runoff module usually takes the $CN_{II}$ (medium Antecedent Runoff Conditions) as a parameter from which $CN_I$ and $CN_{III}$ are deduced (NRCS, 2004).

#### 2.1.2. Vineyard crop model

Our case study is a vineyard water balance model (Gaudin and Gary, 2012) used for estimating the dynamics of vineyards water stress. The model performs a water balance with a single tipping bucket approach as in (Lebon et al., 2003) together with the NRCS runoff module. The main model output is the daily fraction of transpirable soil water ($FTSW^t$). The water balance equation that allows $FTSW^t$ to be computed from $FTSW^{t-1}$, daily precipitation $P^t$, daily runoff $\widehat{Q}^t$, daily evaporation $E^t$, daily vineyard transpiration $T^t$ and Total Transpirable Soil Water (TTSW) is given in Equation (2):

$$FTSW^t = \min\left(1, \max\left(0, FTSW^{t-1} + \frac{1}{TTSW}\left(P^t - \widehat{Q}^t - E^t - T^t\right)\right)\right) \quad (2)$$

In this model the evaporation $E^t$ is estimated using the method from Brisson and Perrier (1991) and the vineyard transpiration $T^t$ is determined using the method from Lebon et al. (2003). The simulated runoff $\widehat{Q}^t$ is computed using the NRCS Curve number method (NRCS, 2004) using the accumulated rainfall to determine the antecedent runoff conditions.

### 2.2. Uncertainty modelling and propagation procedure

We use a two-step approach to estimate the structure uncertainty coming from the runoff process: First, we produce an uncertainty estimate of runoff for a single runoff event; Then this uncertainty is propagated using a mathematical property of the model. This is explained in the following sections.

#### 2.2.1. Runoff uncertainty modelling

We propose a simple method to produce the uncertainty estimate of a runoff event $Q^t$. The uncertainty of the module is acknowledged in (NRCS, 2004; Hjelmfelt, 1991; Young and Carleton, 2006) particularly because of the difficulty to find accurate predictions of experimentally determined values of $CN^t$ using causative mechanisms. However while the variability of $CN^t$ values is difficult to explain, some quantiles of the distribution are reported to be reliable. More precisely (NRCS, 2004; Hjelmfelt, 1991; Young and Carleton, 2006), state that $CN_I$ and $CN_{III}$ can be interpreted as the 10*th* percentile and the 90*th* percentile of the distribution of $CN^t$ values. This means that while it is difficult to provide a reliable estimate of $CN^t$ within the range $[CN_I, CN_{III}]$, *this range correctly captures the variability of possible* $CN^t$. This property can be used to produce an uncertainty estimate of a runoff event $Q^t$: Let $\widehat{Q}^t_{CN_I}$ and $\widehat{Q}^t_{CN_{III}}$ be the runoff estimates associated to a rainfall $P^t$ with respectively $CN = CN_I$ and $CN = CN_{III}$, the reliable range hypothesis on $CN^t$ combined with the monotony of $\widehat{Q}^t(CN, P^t)$ with respect to $CN$ implies that the true value $Q^t$ verifies:

$$\widehat{Q}^t_{CN_I} \leq Q^t \leq \widehat{Q}^t_{CN_{III}} \quad (3)$$

Young and Carleton (2006) used this property to generate random values of $Q^t$ from a distribution of $CN^t$ values based on $CN_I$ and $CN_{III}$. The drawback of this stochastic approach is the number of simulations that is required to estimate the distribution of the model output. This sampling issue is particularly present when the random generator is called numerous times by the model, which is the case in a crop model calling the runoff module for every rainfall event. That is why we introduce in the next section another propagation procedure that relies on a mathematical property of the crop model. It is less precise than the stochastic approach but requires only two simulations.

#### 2.2.2. Propagation principle

The propagation procedure is based of the following idea: If a model input varies in a range whose bounds are known, the model output may vary between the values of the model at bounds. This property is ensured *if the model is monotonic with respect to the considered input.*