# Evaluation of modelled and measured evaporation from a bare Vertosol soil in south east Queensland, Australia

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**Abstract:** Soil evaporation is often the largest component of the soil water balance in farming systems across south east Queensland, Australia. Any errors in modelling this component will have significant flow-on effects on modelled estimates of other components such as transpiration, runoff and deep drainage. Parameterization of soil evaporation in models is still, at times, an intuitive and experience based process. Recent lysimeter studies measured bare soil evaporation for a range of Queensland soils and have provided a considerable dataset with which to validate soil water balance models and improve confidence in the parameters used.

Here we evaluate soil evaporation estimated by the HowLeaky soil water balance model against measured soil evaporation during 2010 to 2012 for a Black Vertosol soil. The HowLeaky model uses two parameters, *U* and *C* (CONA), to specify soil evaporation. *U* (stage 1 drying) is the amount of cumulative evaporation since soil wetting before soil supply becomes limiting and *C* (stage 2 drying) is the subsequent soil evaporation as a fraction of the square root of time since the end of *U*. A range of commonly used *U* values, 2 to 7.5, and *C* values, 3 to 5.6, were evaluated.

The modelled soil evaporation trends agreed well with the measured trends when *U* and *C* values were adjusted. The cumulative percent difference between the measured and the modelled soil evaporation at various time points suggested that the model generally underestimated soil evaporation. However, use of the model with low *U* value of 2 and high *C* value of 5.6 gave a better approximation of soil evaporation rates than higher *U* and lower *C* values. Seasonal difference in the modelled and measured soil evaporation was apparent due to use of only one set of *U* and *C* values by the model across the seasons. However, the cumulative difference between measured and modelled soil evaporation decreased over longer time frames (i.e. 3 years) suggesting that the model is reasonable at predicting long-term soil evaporation. Prediction of soil evaporation on shorter time frames (seasonal or yearly) would be improved by using season specific *U* and *C* values in the model. The study highlights the importance of utilizing measured data for improved predictions by the model. The findings have broader applicability to models that apply the Ritchie's algorithm in predicting the soil evaporation components of water balance.

***Keywords:*** *Clay, HowLeaky model, lysimeter, soil water balance, validation*

## 1. INTRODUCTION

Soil evaporation is a major component of the soil water balance, especially in dryland farming in south east Queensland where soil evaporation can be 65 to 70% of fallow rainfall (Gardner et al., 1988; Freebairn et al., 1997). Therefore, soil evaporation should be assessed in order to develop feasible management practices for storing and conserving water within the soil profile.

Water balance models are commonly used to estimate soil evaporation because of their ease of use, relative cost effectiveness compared with direct measurement (e.g. lysimeters) and their suitability for a wide range of growing conditions and climates. Precise estimation of soil evaporation depends on the model's ability to represent realistic conditions. Validation against measured data, when available, is therefore an essential and ongoing step in agricultural and environmental modelling. This validation process tests a model's accuracy and identifies the range of physical and temporal conditions under which the predictions are credible (Jakeman et al., 2006).

HowLeaky (Rattrey et al., 2004; Robinson et al., 2010) is a popular model commonly used in Australia to estimate various components of the soil water balance. HowLeaky, or PERFECT (Littleboy et al., 1999), the pre-cursor model to HowLeaky, has been validated under a wide range of growing conditions in Queensland (Abbs and Littleboy, 1998; Ranatunga et al., 2008). However, the evaporation component used in HowLeaky has not been rigorously tested due to lack of measured soil evaporation data. Recent studies have measured bare soil evaporation for a range of Queensland soils, providing a considerable dataset to validate the soil evaporation component of water balance models and improve confidence in the parameters used.

The objectives of this study were to evaluate HowLeaky's ability to simulate bare soil evaporation for a Black Vertosol soil from south east Queensland, and provide a guide to better parameterise and estimate soil evaporation using HowLeaky.

## 2. METHODS

### 2.1. Model

The water balance of a bare fallow condition was simulated using the HowLeaky model. HowLeaky is a one-dimensional mechanistic model that is based on the well-established water balance components of PERFECT V.3 (Littleboy et al., 1999). Daily soil water balance in HowLeaky is simulated using a 'cascading bucket' approach with multiple soil layers. Runoff is calculated using the modified USDA runoff model (Littleboy et al., 1996). When the soil water content of a given layer exceeds drained upper limit, water moves to the soil layer below at a rate no higher than a specified daily limit. Water that moves below the maximum soil depth is considered deep drainage.

Soil evaporation components in HowLeaky are based on the modified Ritchie's two stage evaporation (drying) algorithm (Ritchie, 1972). Stage 1 drying is the amount of cumulative evaporation since soil wetting before soil supply becomes limiting, whereas stage 2 drying is the subsequent soil evaporation as a fraction of the square root of time since the end of stage 1 drying. Stage 1 and stage 2 drying are represented respectively by the term $U$, the upper limit of stage 1 drying; and $C$ (CONA), the slope of the stage 2 drying curve when cumulative soil evaporation is plotted against the square root of time. In HowLeaky, stage 1 drying recommences after any rainfall event that is greater than $U$ value. Stage 1 drying will equal the potential soil evaporation rate until the cumulative stage 1 drying exceeds the $U$ value. Cumulative stage 1 drying is reduced by any amount of infiltration that occurs (Littleboy et al., 1999). This contrasts to the original Ritchie's algorithm where all cumulative stage 2 drying had to be refilled by infiltration before stage 1 drying could recommence. When this limit is exceeded, stage 2 drying commences based on Ritchie (1972). Stage 2 evaporation = $C\,(t^{0.5}-(t-1)^{0.5})$, where $C$ = CONA, t = days since rainfall.

### 2.2. Validation data sets

Three years of measured soil evaporation data (20010-2012) were collected from a weighing lysimeter facility at Kingsthorpe, south east Queensland (151°47' E, 27°30') and used to validate the HowLeaky model. The lysimeters are encased undisturbed soil monoliths (0.56 m circular diameter and 0.8 m deep) resting on weighing strain gauges (3 under each lysimeter). Lysimeter weights are logged every 15 minutes and changes are attributed to either evaporation losses or weight gains from natural rainfall. Excess water accumulated in the bases of lysimeters after heavy rainfall is manually collected by applying a suction of 10 kPa to a set of ceramic cups installed in the bases of each lysimeter. A rainout shelter is selectively used to cover the lysimeters during some rain events to collect longer duration drying curves. The lysimeter facility hosts a range of soil types (four replicates for each soil type) and two water filled lysimeters. This paper presents the results for the Black Vertosol (Isbell, 1996) with average clay content of 69%.

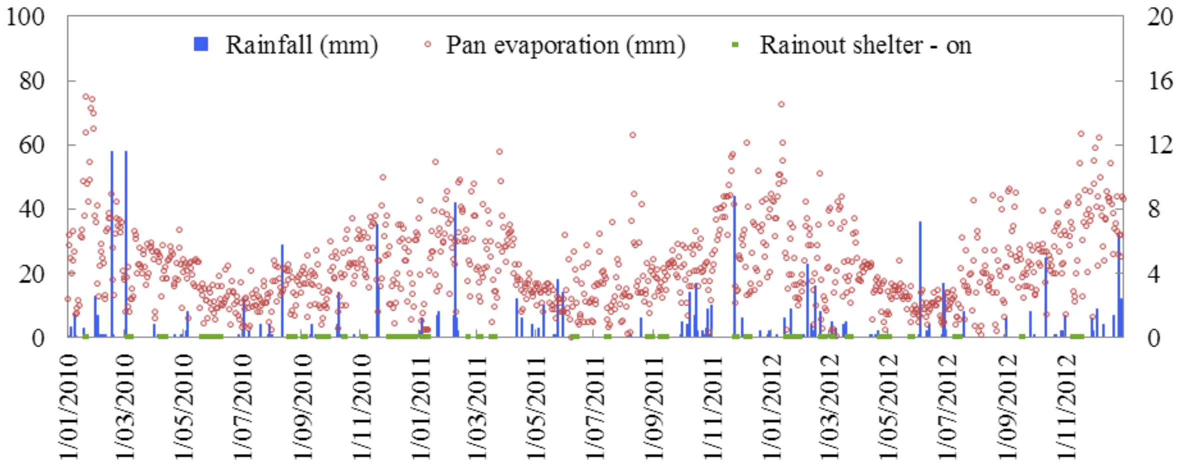


**Figure 1.** Daily rainfall (left axis) and daily pan evaporation (right axis) for the study site at Kingthorpe, south east Queensland.

## 2.3. Model parameterization

Maximum and minimum temperature, solar radiation, vapour pressure, and rainfall data (Figure 1) were obtained from a climate station established at the study site. Daily evaporation measured by the water filled lysimeters was used to represent the pan evaporation (Figure 1) as this provided the most accurate and realistic data to account for the conditions experienced on-site and during periodic short term covering (1-3 days) with the rainout shelter. A complete hydraulic characterization of the soil was undertaken to obtain maximum daily drainage, bulk density, volumetric soil water contents at saturation, drained upper limit, drained lower limit and starting water contents. A runoff curve number (i.e. runoff as a function of total daily rainfall) value which describes runoff potential for bare soil and also maximum daily drainage values were according to Owens et al. (2004) and Jenny Foley (personal communication).

**Table 1.** Soil parameters used in the HowLeaky model for a Black Vertosol soil at Kingsthorpe, south east Queensland.

| Detail | Unit | Value (selective depth) | | | |
|---|---|---|---|---|---|
| Layer depth | m | 0.1 | 0.3 | 0.6 | 0.8 |
| Air dry water content | % (v/v) | 20 | 21 | 15 | 13 |
| Drained upper limit water content | % (v/v) | 53 | 53 | 51 | 47 |
| Drained lower limit water content | % (v/v) | 33 | 32 | 36 | 37 |
| Maximum daily drainage | mm/day | 100 | 35 | 35 | 0.1 |
| Bulk density | g/cm³ | 0.9 | 1.0 | 1.1 | 1.1 |
| | | Value (for all depth) | | | |
| Evaporation, stage 1 drying (*U*) | mm | 2 to 7.5 | | | |
| Evaporation, stage 2 drying (*C*) | $mm/day^{0.5}$ | 3 to 5.6 | | | |
| Runoff curve number for bare soil | | 50 | | | |
| Field slope | % | 0 | | | |
| Curve number reduction at 100% cover | | 18 | | | |

Four sets of *U* and *C* values were tested, i) *U* 5 and *C* 3, used commonly in APSIM modelling (McCown et al., 1996) for south east Queensland, ii) *U* 7.5 and *C* 3.5, based on clay content (Ritchie and Crum, 1989), iii) *U* 2 and *C* 5.6, empirically derived from the lysimeter data (Jenny Foley, personal communication), and iv) *U* 2 and *C* 3, assumed to represent a low *U* and low *C* for the studied conditions. Fallow conditions were simulated as bare soil using the dynamic crop module within HowLeaky by forcing vegetation to terminate immediately after planting. The fraction of plant-available water capacity in the soil profile at the start of the simulation was set to 0.78 to reflect the measured water content at the beginning of study. Simulations ran from January 2010 to December 2012. Soil evaporation was interpreted as either a weekly total (sum of 7 days) or as a cumulative (progressive sum). The cumulative percent difference in soil evaporation was used to interpret the differences among various data sets at various time points.

## 3. RESULTS AND DISCUSSION

The results show a reasonable similarity between modelled and measured soil evaporation trends on a weekly total basis (Figure 2). The study location was characterized by summer dominant rainfall that coincided with high pan evaporation, with lower rainfall and lower pan evaporation for the other seasons (Figure 1). Therefore, significant wetting-drying events were most evident in summer (Figure 2). Each significant rainfall event corresponded to an increase in the soil evaporation for a short period (stage 1 drying) due to ample moisture supply, followed by a gradual decrease (stage 2 drying). The model captured these stages accordingly.

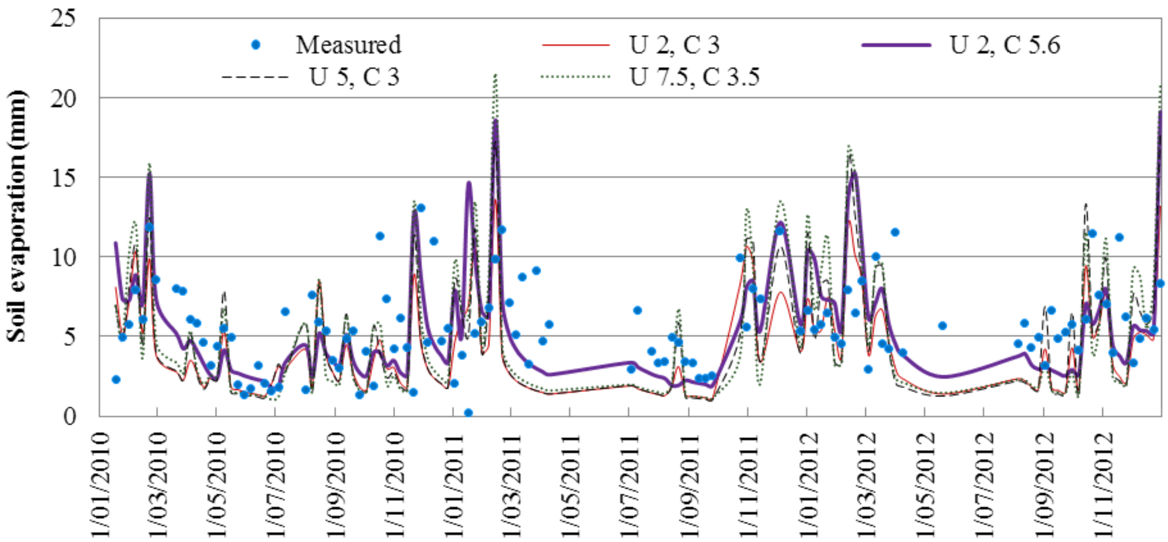


**Figure 2.** Measured soil evaporation and the modelled soil evaporation for four sets of *U* and *C* values on a weekly total basis for a Black Vertosol soil under bare fallow conditions at Kingsthorpe, south east Queensland.

The modelled estimates of cumulative soil evaporation for all sets of *U* and *C* were lower than measured data (Figure 3). This suggests that the model generally underestimated soil evaporation. The low *U* and high *C* of 2 and 5.6 gave the best agreement with the measured soil evaporation both on weekly (Figure 2) and cumulative basis (Figure 3), as these values were derived from the measured dataset. For example, by the end of the study, the cumulative soil evaporation was 691 mm for the measured data and 642 mm for modelled *U* and *C* of 2 and 5.6 (-7% difference) as against 494 mm (-29%), 553 mm (-20%) and 589 mm (-15%), respectively for *U* and *C* of 2 and 3, 5 and 3, and 7.5 and 3.5 (Figure 3). This suggests that *U* and *C* of 2 and 5.6 best represent bare fallow soil evaporation for Black Vertosol under the studied conditions. This agrees with Yunusa et al. (1994) who suggests low *U* and high *C* for ensuring reliable estimates of soil evaporation in the Ritchie model for dry climates with wide fluctuations in soil evaporation.

Seasonal difference between measured and modelled soil evaporation was apparent, particularly between extremes of rainfall and evaporative periods. For example, from mid-January to mid-March in 2011 and 2012, the difference for *U* and *C* of 2 and 5.6 was respectively only 0 to -8% and -2% to -7%, but was -9 to -11% and -5 to -8% from mid-August to mid-November in 2011 and 2012 (Figure 3). We used only one set of *U* and *C* for a given simulation and hence the difference in the soil evaporation between seasons was expected. Nevertheless, the overall difference was somewhat similar when simulated across the seasons. For example, for *U* and *C* of 2 and 5.6, the difference was -3% by the end of February in both 2011 and 2012 (Figure 3). That is, the difference created by the model for each season was somewhat cancelled out when simulated across all seasons of a year.

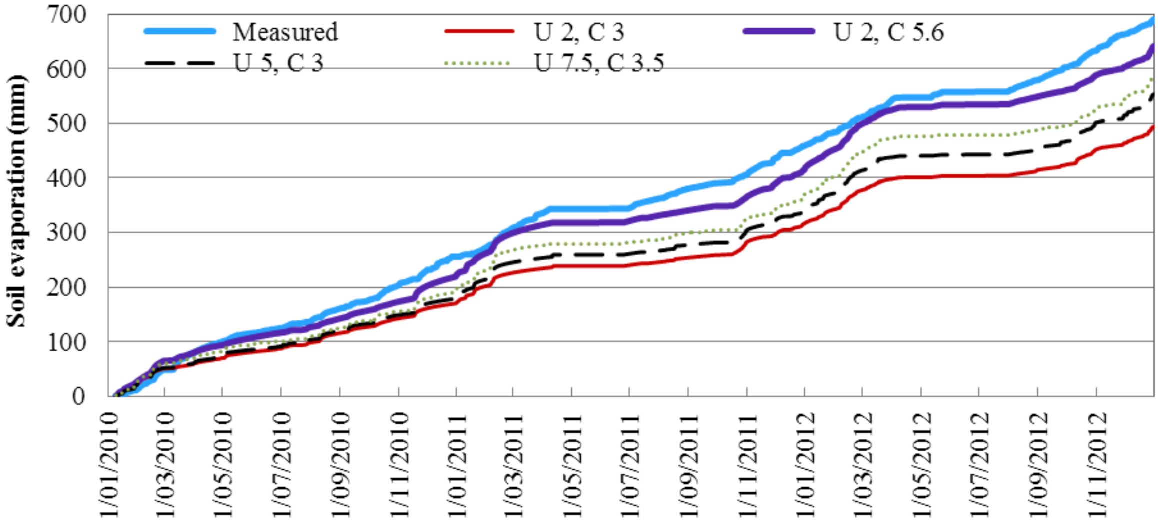


**Figure 3.** Measured soil evaporation and the modelled soil evaporation for four sets of *U* and *C* values on a cumulative basis for a Black Vertosol soil under bare fallow conditions at Kingsthorpe, south east Queensland.

The difference also decreased over longer time frames. The difference ranged from -14 to -34% by the end of first year but decreased by 3 to 4% (-10 to -31%) in the second year and a further 2 to 3% (-7 to -29%) in the third year, for various sets of *U* and *C* (Figure 3). This suggests that prediction efficiency by the model was improved when soil evaporation was studied for longer durations by accounting for inter and intra year variations in climate.

The results can be extended to other areas with some considerations. In HowLeaky, stage 1 evaporation depends on the potential soil evaporation until cumulative soil evaporation reaches a given *U* value. Whereas, the stage 2 soil evaporation is assumed to be dependent mainly on soil moisture conditions and soil hydraulic properties (Ritchie, 1972; Yunusa et al., 1994), thereby ignoring the effects of potential soil evaporation. Therefore, under the current modelling assumptions, measured *U* and *C* values from a known soil type can be extended to certain degree for other climates provided the soil characteristics are similar. However, studies showed that both *U* and *C* values are sensitive to potential soil evaporation (Jalota and Prihar, 1987; Yunusa et al., 1994; M. Silburn, D. Freebairn, personal communication). In these cases, *C* values in HowLeaky can be further adjusted. For example, a higher *C* value of 6.5 was used for Goondoola basin study in south western Queensland (Robinson et al., 2010) that had higher pan evaporation rates than this study. Future improvements to the HowLeaky model should consider a wider range factors that affect soil evaporation to improve estimates of soil evaporation.

## 4. CONCLUSIONS

The HowLeaky model captured the general trends in the measured soil evaporation when *U* and *C* values were adjusted. A lower *U* value of 2 and a higher *C* value of 5.6 can be used to represent the soil evaporation under the studied conditions better than higher *U* and lower *C* values. The study highlights the importance of utilizing measured data for improved predictions by the model. The findings have broader applicability to models that apply the Ritchie's algorithm in predicting the soil evaporation component of water balance.

Predictions were improved when modelled across seasons and for longer duration by accounting for climate variations. This suggests that the model can be used with greater confidence when soil evaporation is studied over longer time frames. Differences among the seasons in the modelled and measured soil evaporation were inevitable, but can be minimized through the use of season specific *U* and *C* values in the model. However, the study is for only one soil type and hence validation for other soil types is needed to extend the model's applicability to a wider range of cropping soils.

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**REFERENCES**

Abbs, K. and Littleboy, M. (1998). Recharge estimation for the Liverpool Plains. *Australian Journal of Soil Research*, 36, 335–357.

Freebairn, D.M., Lawrence, D., Wockner, G.H., Cawley, S. and Hamilton, A.N. (1997). A framework for extending principles of conservation cropping. In, Farming systems research – two decades on (Ed. Edwards, J.), NSW Agriculture: Moree. pp 22–29.

Gardner, E.A., Coughlan, K.J. and Silburn, D.M. (1988). Soil water measurement and management on vertisols in Queensland, Australia. In, Management of Vertisols in Sub-Saharan Africa (Eds. Jutzi, S.C., Haque, I., McIntire, J. and Stares, J.E.S.), International Livestock Centre for Africa, Addis Ababa, Ethiopia, 1988. pp. 131–165.

Isbell, R. (1996). The Australian soil classification. CSIRO, Melbourne.

Jakeman, A.J., Letcher, R.A. and Norton, J.P. (2006). Ten iterative steps in development and evaluation of environmental models. *Environmental Modelling and Software*, 21, 602–614.

Jalota, S.K. and Prihar, S.S. (1987). Observed and predicted trends from a sandy loam soil under constant and staggered evaporativity. *Australian Journal of Soil Research,* 25. 243–249.

Littleboy, M., Cogle, A.L., Smith, G.D., Yule, D.F. and Rao, K.P.C. (1996). Soil management and production of Alfisols in the semi-arid tropics. I. Modelling the effects of soil management on runoff and erosion. *Australian Journal of Soil Research,* 34, 91–102.

Littleboy, M., Freebairn, D.M., Silburn, D.M., Woodruff, D.R. and Hammer, G.L. (1999). PERFECT: A computer simulation model of Productivity Erosion Runoff Functions to Evaluate Conservation Techniques. Queensland Department of Primary Industries, Queensland.

McCown, R. L., Hammer, G. L., Hargreaves, J. N. G., Holzworth, D. P. and Freebairn, D. M. (1996) APSIM: A novel software system for model development, model testing, and simulation in agricultural systems research. *Agricultural Systems,* 50, 255–271.

Owens, J.S., Tolmie, P.E. and Silburn, D.M. (2004). Validating modelled deep drainage estimates for the Queensland Murray–Darling Basin. In, Conserving Soil and Water for Society: Sharing Solutions, (Raine, S.R., Biggs, A.J.W., Menzies, N.W., Freebairn, D.M. and Tolmie, P.E. Eds.). Australian Society of Soil Science Inc., Warragul, Victoria.

Ranatunga, K., Nation, E.R. and Barratt, D.G. (2008). Review of soil water models and their applications in Australia. *Environmental Modelling and Software,* 23, 1182–1206.

Rattray, D.J., Freebairn, D.M., McClymont, D, Silburn, D.M., Owens, J. and Robinson, J.B. (2004). HOWLEAKY? The journey to demystifying simple technology. In, Conserving Soil and Water for Society: Sharing Solutions (Raine, S.R., Biggs, A.J.W., Menzies, N.W., Freebairn, D.M. and Tolmie, P.E. Eds.). Australian Society of Soil Science Inc., Warragul, Victoria.

Ritchie, J.T. (1972). A model for predicting evaporation from a row crop with incomplete cover. *Water Resources Research*, 8, 1204–1213.

Ritchie, J. T. and Crum, J. (1989). Converting soil survey characterisation data into IBSNAT crop model input. In, Land Qualities in Space and Time, proceedings of a symposium organised by the International Society of Soil Science, Wageningen, The Netherlands, Pudoc, Wageningen. pp. 155–68.

Robinson, J.B., Silburn, D.M., Rattray, D., Freebairn, D.M., Biggs, A., McClymont, D. and Christodoulou, N. (2010). Modelling shows that the high rates of deep drainage in parts of the Goondoola Basin in semi-arid Queensland can be reduced with changes to the farming systems. *Australian Journal of Soil Research,* 48, 1–11.

Yunusa, I.A.M., Sedgley, R.H. and Tennant, D. (1994). Evaporation from bare soil in south-western Australia: a test of two models using lysimetery. *Australian Journal of Soil Research,* 32, 437–446.