Review of the "Validation Report of *ecosys* Version 1.0"[1]

Prepared for the Climate Action Reserve (CAR) by HabiTerre

Dated: January 29, 2024

in adherence with the CAR *Requirements and Guidance for Model Calibration, Validation, Uncertainty, and Verification for Soil Enrichment Projects, Version 1.1a*[2]

Reviewer: David I Gustafson, Ph.D. (Independent Scientist, gustafson@ctic.org)

Summary

The *ecosys Validation Report* was for Type 2 validation: i.e., "generalized to demonstrate overall performance … where model performance is valid over a range of possible project domains and crop functional group/practices category combinations".[3]

All requirements of the *SEP Model Requirements* were specifically met, except where otherwise noted in this review.

The *ecosys* model (version 1.0) effectively met the bias requirement and the error requirement that 90% of measurements fell within the 90% prediction interval. Therefore, the model is acceptable for application in the following domain:

Crop Functional Types (CFT)	Corn, an annual, C4, herbaceous, non-N-fixing, non-flooded crop Soybeans, an annual, C3, herbaceous, N-fixing, non-flooded crop
Emission Sources (ES)	SOC changes Direct N_2O emissions
Practice Categories (PCs)	Cropping practices (e.g., cover crops) Inorganic nitrogen fertilizer application Organic amendments application of manure (not for Soybeans) Soil disturbance and/or residue management (e.g., tillage)
Soil Texture Classes & Soil Clay Content	LS, SL, SiL, L, SCL, SiCL, CL, SiC & Clay content range: 4-48%
Land Resource Regions (LRR)	F, G, H, K, L, M, N, P
IPCC Climate Types	Cool Temperate Moist & Dry (CTM, CTD) Warm Temperate Moist (WTM)

The validation dataset includes only one site for the impact of inorganic fertilizer applications on direct N_2O emissions in soybeans, so this reviewer recommends that when additional data become available, the report should be updated with any additional data included and the validation and model prediction error reassessed.

Similarly, with regard to the impact of organic amendments (i.e., manure), the domain includes only its effect on SOC changes and direct N_2O emissions in corn, and the range of soil types is limited to CL, SiL, and L.

With regard to soils, the overall validation domain includes loamy sand (LS), sandy loam (SL), silt loam (SiL), loam (L), sandy clay loam (SCL), silty clay loam (SiCL), clay loam (CL), and silty Emission Source (ES) for three of these soil types (LS, SCL, SL), but these soils are relatively rare

---

[1] Hereinafter referred to as the "*ecosys Validation Report.*"

[2] Hereinafter referred to as the "*SEP Model Requirements.*"

[3] *SEP Model Requirements*, p 23.

in the corn and soybean growing areas within the claimed Land Resource Regions (LRRs), so there is no significant concern associated with including them within the validation domain.

Similarly, with regard to LRR coverage, there is only one validation site per ES for six of these LRRs (F, G, H, K, L, P). However, all ES/LRR combinations have at least one site (P has two SOC sites) and it is the professional opinion of this reviewer that these lesser-covered regions are sufficiently similar to the corn and soybean growing areas of neighboring regions that there is no significant concern associated with including any of them within the overall validation domain.

The validation domain includes three IPCC Climate Types: Cool Temperate Moist (CTM), Cool Temperate Dry (CTD), and Warm Temperate Moist (WTM).

Model Calibration

As explained in Section 4 and Appendix A of the *ecosys Validation Report*, HabiTerre chose to use a default set of model input parameters that had been calibrated in previous published studies, where they did not employ their preferred method of parameter calibration, which they have designated as "advanced model-data fusion (MDF)."[4] They were prevented from deploying the MDF technique based on the constraints of the current *SEP Model Requirements*. Accordingly, HabiTerre has proposed that CAR consider modifications of this document to permit MDF to be deployed in future validation reports.

HabiTerre asserts that none of the data used in this current model validation effort had been utilized in the development or previous calibration of *ecosys,* which dates back nearly 30 years. It is also noteworthy that the more recent modeling studies reported by HabiTerre did not use any observations of SOC changes or direct N_2O emissions as constraints.[5] Accordingly, the data used for validation of *ecosys* were not used for calibration, as specified in the *SEP Model Requirements*.

Completeness Check: Section 2 of the *SEP Model Requirements*

Section 2 of the *SEP Model Requirements* lists the following required elements for each validation report.[6] These have been fulfilled within the indicated sections of the *ecosys Validation Report*, or rendered "Not Applicable" (N/A) as described below.

Model version	Section 1.4
Description of the model calibration process	Section 4
Documentation of all model input parameters	Section 5, Appendix B
Justification for variation of model input parameters	N/A[7], see Section 4

---

[4] *ecosys Validation Report*, p 8.
[5] *ecosys Validation Report*, p. 8.
[6] *SEP Model Requirements*, p 9.
[7] "Not Applicable"

Justification for splitting of calibration & validation data	N/A, see Section 4

In Section 1.4 of the *ecosys Validation Report*, HabiTerre makes it clear that the company has full control of the version of *ecosys* used in its work and in the report. This version is no longer identical to the version originally developed at the University of Alberta and released publicly released in 2019. Starting with this publicly released version, HabiTerre has adapted and maintained an internal version of the model, which is referred to within the report as *ecosys* version 1.0.

As explained in Section 4 and Appendix A of the *ecosys Validation Report*, HabiTerre chose to not use its preferred method of model calibration (MDF), as this method is not compliant with the current *SEP Model Requirements*. This reviewer supports the assertion by HabiTerre that there would be some merit in allowing such calibration to take place in the current context. However, given that no such calibration was performed, this rendered the final two elements in the above list to become N/A.

In addition to fulfillment of these requirements, HabiTerre has indicated that it can make available the following information upon request by the CAR Verification Team: datasets used for model validation, including but not limited to full citation, experimental locations, specific crops and practices studied, LRRs and IPCC climate zones, soil textures and clay contents, and number of observations. There is rigorous archiving of *ecosys* Version 1.0, including all input parameters.

Completeness Check: Section 3.2 of the *SEP Model Requirements*

Section 3.2 of the *SEP Model Requirements* lists the following required elements for Type 2 validation reports.[8] These have been fulfilled within the indicated sections of the *ecosys Validation Report*.

List of combinations of PCs, CFTs, and ESs validated	Sections 6.1, 6.2, 6.5, Tables 2, 3, 7 & Appendix D
LRRs and IPCC climate zones for which each combination is validated	Section 6.3, Tables 4 & 5
List of soil texture classes and associated clay contents for which each combination is validated	Section 6.4, Table 6 & Appendix D

As explained in the Summary section of this report, the validation dataset includes only one site for the impact of inorganic fertilizer applications on direct N_2O emissions in soybeans, so this reviewer recommends that when additional data become available, the report should be updated with any additional data included and the validation and model prediction error reassessed. Similarly, with regard to the impact of organic amendments (i.e., manure), the domain includes only its effect on SOC changes and direct N_2O emissions in corn, and the range of soil types is limited to CL, SiL, and L.

With regard to soils, the overall validation domain includes loamy sand (LS), sandy loam (SL), silt loam (SiL), loam (L), sandy clay loam (SCL), silty clay loam (SiCL), clay loam (CL), and silty clay (SiC) – covering a broad range of clay content (4 - 48%). There is only one validation site per Emission Source (ES) for three of these soil types (LS, SCL, SL), but these soils are relatively rare

---

[8] *SEP Model Requirements*, p 11-12.

in the corn and soybean growing areas within the claimed Land Resource Regions (LRRs), so there is no significant concern associated with including them within the validation domain.

Similarly, with regard to LRR coverage, there is only one validation site per ES for six of these LRRs (F, G, H, K, L, P). However, all ES/LRR combinations have at least one site (P has two SOC sites) and it is the professional opinion of this reviewer that these lesser-covered regions are sufficiently similar to the corn and soybean growing areas of neighboring regions that there is no significant concern associated with including any of them within the overall validation domain.

The validation domain includes three IPCC Climate Types: Cool Temperate Moist (CTM), Cool Temperate Dry (CTD), and Warm Temperate Moist (WTM).

Completeness Check: Section 3.3 of the *SEP Model Requirements*

Section 3.3 of the *SEP Model Requirements* lists the following required elements for all validation reports.[9] These have been fulfilled within the indicated sections of the *ecosys Validation Report*.

Full description of data requirements to initialize and run the model version and parameter sets accurately, as well as the process for addressing missing information	Sections 5, 7.2
A full accounting of the studies comprising the validation dataset for each CFT/PC/ES combo, for each emissions source. Study attributes should include: Citation, LRR and IPCC climate zone, PC and CFTs being studied, Soil texture(s) and clay contents being studied, Experimental time period, Depths of SOC measurements, Measurement technique, e.g., dry combustion for SOC, or chambers for N_2O, Methods of temporal aggregation used for observations of N_2O and CH_4, Portions of the calendar year covered by all N_2O and/or CH_4 measurements, with justification provided when portions are missing, Number of observations used in validation, Measurement uncertainty associated with replicates, where reported.	Section 7; Appendix D

For all PC/CFT/ES combinations, at least 3 soil textural classes must be present and must span at least 15 percentage points for clay content. Although soil type is missing from Table 7 in the *ecosys Validation Report*, examination of the more detailed information available in Appendix D confirms that this requirement has been fulfilled for all PC/CFT/ES combinations, with the exception of the Organic PC (i.e., manure) in Corn for which there are only two soil types each for both SOC changes (CL, SiL) and direct N2O emissions (L, SiL).

---

[9] *SEP Model Requirements*, p 16.

All of the critical data elements required by the *SEP Model Requirements* for validation studies have been reported in the *ecosys Validation Report*. The few that have not been included (e.g., ES measurement technique) are judged by this reviewer to not be essential for addressing the overall validity of *ecosys*.

Completeness Check: Section 3.4 of the *SEP Model Requirements*

Section 3.4 of the *SEP Model Requirements* lists the following required elements for all validation reports.[10] These have been fulfilled within the indicated sections of the *ecosys Validation Report*, with the exception of a deviation described below.

One complete example derivation of: Calculation of model bias for a study, per Figure 3.1; Calculation of PMU for a single measurement technique, per Figure 3.2	Section 9.2 (PMU) and Section 9.3 (bias)
All values of PMU used for each PC/CFT/ES combination validated.	Section 9.3; Table 9
All values of study bias for each study in a PC/CFT/ES's validation dataset, ranked highest to lowest	Section 9.4; Table 10 (SOC); Table 11 (N2O) Appendix G
Average bias across all studies in a PC/CFT/ES's validation dataset.	Section 9.3; Table 9 Appendix G

As documented in an email-exchange with McKenzie Smith of CAR (see Appendix F), it was agreed that there were insufficient data available to avoid pooling validation data across practices (PC) and crops (CFT), in order to have sufficient information for a statistically-meaningful comparison of bias with pooled measurement uncertainty. This deviation from the *SEP Model Requirements* was provisionally approved, pending overall CAR review of the *ecosys Validation Report*. Appendix G contains summarized tabular statistics for specific practices (unpooled). However, the additional data provided in Appendix G are not intended to be used for quantitative purposes.

Completeness Check: Section 3.5 of the *SEP Model Requirements*

Section 3.5 of the *SEP Model Requirements* lists the following required elements for all validation reports.[11] These have been fulfilled within the indicated sections of the *ecosys Validation Report*.

For each PC/CFT combination by ES: Graphs of measured vs, modeled results demonstrating that the 90% prediction intervals contain the measured value at least 90% of the time, per Figure 3.3; Scatterplot of the model predictions vs. measurements; Histograms of residuals; Mean squared error	Section 10; Appendix G

---

[10] *SEP Model Requirements*, p 20.
[11] *SEP Model Requirements*, p 23.

Documentation of final parameter sets and model prediction error for each emissions source (per Appendix D.1)	Section 10; Appendix G

As noted above and documented in Appendix F, CAR has provisionally approved the pooling of data across practices and crops, and this is the format used in Section 10. The pooled scatterplots are provided as Figure 7 (SOC) and Figure 9 (N_2O). The pooled histograms are provided as Figure 8 (SOC) and Figure 10 (N_2O). The pooled mean square error for SOC changes is 0.140 Metric Tons (MT) CO_2e acre-1 year-1, averaged across all practice categories and crops. The confidence coverage rate is 94.8%, fully compliant with the *SEP Model Requirements*. The pooled mean square error for direct N2O emissions is 0.030 MT CO_2e acre-1, averaged across all practice categories and crops. The confidence coverage rate is 93.1%, which is again fully compliant with the *SEP Model Requirements*.

Appendix G contains scatterplots, histograms and mean square errors for specific practices (unpooled). However, the additional data provided in Appendix G are not intended to be used for quantitative purposes.

Model Performance and Uncertainty

As discussed briefly above and in more detail within Appendix A of the *ecosys Validation Report*, HabiTerre has demonstrated that model performance would be significantly enhanced through the use of their published "Model Data Fusion" (MDF) calibration process. Nevertheless, the validation report provides convincing evidence for the ability of the uncalibrated *ecosys* model (designated Version 1.0) to effectively simulate the impact of four important climate-smart practices (cover cropping, reduced tillage, inorganic fertilizer management, and organic amendments) on changes in SOC and direct N_2O emissions in corn and soybeans – with the important caveats that this reviewer recommends that when additional data become available, the report should be updated with any additional data included and the validation and model prediction error reassessed for N_2O emissions changes for fertilizer management in soybeans and for the effect of organic amendments on either ES in soybeans.

As explained in the email exchange documented in Appendix F, the validation data were pooled across the entire domain, rather than for each PC/CFT/ES combination. Appendix G contains scatterplots, histograms and mean square errors for specific practices (unpooled). However, the additional data provided in Appendix G are not intended to be used for quantitative purposes.

The soil texture classes and their clay contents were listed, as were the Land Resource Regions and IPCC Climate Types. Taken as a whole, the validation domain is sufficiently representative for most US regions where corn and soybeans are grown, with an unsurprising focus on the midwestern US (i.e., the "Corn Belt").

The *ecosys Validation Report* adequately describes the procedures used to derive the model bias and PMU, including the provision of example derivations.

Accordingly, it is determined that all specifications listed in the *SEP Model Requirements* for assessing the performance and uncertainty of *ecosys* Version 1.0 have been effectively met by the *ecosys Validation Report*.

Appendix 1. Reviewer Requests and Responses during the Review Process

Request	Response
Multiple suggested edits to a first version of the *ecosys Validation Report*, sent by email on June 12[12], including the need for a new appendix regarding the proposed use of MDF in future validation reports	Appendix A added, describing the use of MDF.
Email inquiry (June 14) regarding the need to clarify whether any of the datasets used in previous development and calibration of *ecosys* could have inadvertently been used for validation. In follow-up email (June 16), suggested content and location of such a clarification (p. 8 of first version).	Resolved via email and edits to the text.
Email notification (June 19) that several of the fields required for "a full accounting of the studies comprising the validation dataset for each CFT/PC/ES combo, for each emissions source" were not present in the *ecosys Validation Report* (see current Appendix D, which contain lists of the studies).	Appendix D (current naming) updated.
Later on June 19, emailed a first draft of this Review for comment and response.	Based on feedback from a second reviewer, a number of additional validation sites were added to the analysis, significantly broadening the validation domain to include all important corn and soybean growing regions of the extended Corn Belt.
Several suggested edits and comments were included in revisions mode to two subsequent drafts of the *ecosys Validation Report*: Version 2.0 (dated July 21) and Version 3.1 (dated November 2).	These edits and comments were all fully addressed in the final version of the report, received on December 20, with only one exception: the HabiTerre team chose not to include a full description of the key members of its Science Team. However, that was only a recommendation of this reviewer and not a specified element of the *SEP Model Requirements*. Importantly, the new version of the report makes it clear that the version of *ecosys* used by HabiTerre is under the company's separate and complete control.

---

[12] All dates listed in this table are for the calendar year 2023.