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Report of Modelling strategy with selected models and model combinations defined

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ETHIOPIA	Water and Land Resources Institute (WLRI)
FINLAND	Finish Environment Institute (SYKE)
ITALY	Centro Internazionale di Alti Studi Agronomici Mediterranei di Bari (CIHEAM-Bari)
ITALY	Italian Research Council (CNR)
KENYA	Kenya Agricultural & Livestock Research Organization (KALRO)
SUDAN	Water Research Centre (WRC)
THE NETHERLANDS	International Soil Reference and Information Center (ISRIC)
UGANDA	Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA)

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Authors (Partner)	ISRIC			
Responsible Authors and contributors	**Name**	Jantiene Baartman, Luuk Fleskens, Joao Nunes, Zhanguo Bai, Janne Juntunen, Nasim Fazel, Alesandra Scardigno, Aymen Sawassi,	**Email**	Jantiene.baartman@wur.nl
	Partner	ISRIC, SYKE, CIHEAM-Bari	**Phone**	+31617634050

Abstract (for dissemination)	Within the WATDEV project, the aim is to simulate the possible impact of scenarios due to the upscale and out-scale of BMPs and Innovations from areas of implementation to large scale/catchment within the study areas and possibly beyond them. For this aim, a modelling toolbox is being developed by the modelling team (SYKE, ISRIC, CIHEAM-Bari), in consultation with the local partners and stakeholders. The aim of the toolbox is to simulate the effect of selected BMPs (Best Management Practices) on environmental and socio-economic indicators for each of the study locations. During various workshops (in Wageningen, NL, Helsinki, Finland and Turin, Italy) and subsequent online meetings, the modelling partners together developed the toolbox. This report describes the steps taken by the modelling team: first, potential models were discussed (section 2) in relation to the BMPs selected by the local partners as well as which indicators were relevant to be simulated for the challenges encountered in each case study. Then, the most suitable models were selected (section 3). Subsequently, a coupling approach was discussed and implemented by SYKE (section 4). Meanwhile, the functionality of the toolbox was discussed, including an approach to post-process some of the direct output of the coupled model further into relevant socio-economic indicators (section 5 and 6). Finally, a potential interface set-up is outlined (section 7).

Keywords	Model strategy; Modelling tool; model selection, SWAT-MODFLOW, DSSAT

Table of Contents

Index of Figures

Index of Tables

Acronyms and Abbreviations

AICS	Italian Agency for Development Cooperation
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa, Uganda
AU-EU	Africa-Europe
CIHEAM	Centre International de Hautes Etudes Agronomiques Méditerranéennes, Italy
CNR-IPSP	Consiglio Nazionale delle Ricerche, Italy
DG DEVCO	The Commission's Directorate-General for International Cooperation and Development
EIARI	Ethiopian Institute of Agricultural Research, Ethiopia
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
HCENR	Higher Council for Environment and Natural Resources, Sudan
HRC	Hydraulics Research Center- Ministry of Water and Irrigation- Gezira, Sudan.
HU	Heliopolis University, Egypt
ISRIC	International Soil Reference and Information Center, The Netherland
IWUA	Irrigation Water Users Association
KALRO	Kenya Agricultural & Livestock Research Organization, Kenya
KU	Khartoum University, Sudan
MCA	Multi-criteria Analysis
NIA	National irrigation Authority, Kenya
NRC	National Research Council, Sudan
R&I	Research and Innovation
SACCO	Savings Credit and Cooperative Organizations
SMA	Sudan Meteorological Authority, Sudan
SOM	Soil Organic Matter
STI	Science, Technology, and Innovation
SYKE	Finnish Environment Institute, Finland
TARDA	TAna River Development Authority, Kenya
WATDEV	Climate Smart WATer Management and Sustainable DEVelopment for Food and Agriculture in North and East Africa
WB	World Bank
WLRC	Water and Land Resources Center, Ethiopia
WMII	Water Management and Irrigation Institute, Sudan
WRC	Water Research Centre, Sudan
WUA	Water User Association
WUE	Water-Use Efficiency

Executive Summary

The Climate Smart WATer Management and Sustainable DEVelopment for Food and Agriculture in East Africa (WATDEV) aims to enhance sustainability of agricultural water management and resilience of agro-ecosystems to climate change in Easter Africa and Egypt. AICS (Agenzia Italiana per la Cooperazione e lo Sviluppo) is the executive agency, CIHEAM-BARI is leading scientific institution working with ASARECA (Strengthening Agricultural Research in Eastern and Central Africa), KALRO (Kenya Agricultural and Livestock Research Organization), WLRC (Water, Land Resources Centre - Ethiopia), WRC (Water Research Centre, Sudan) and HU (Heliopolis University, Egypt). ISRIC (International Soil Reference and Information Centre – The Netherlands) and SYKE Finnish Environment Institute (Finland) are the modelling partners. The overarching objective of the project is to enhance sustainability of agricultural water management and resilience of agro-ecosystems to climate change in East Africa and Egypt. The specific objectives include: (1) National Ministries and Research Institutions improve their knowledge and management of water in agriculture; and (2) Farmers and local actors, cooperatives and Water User Associations implement innovative/sustainable solutions and skills on water management.

A modelling toolbox is being developed by the modelling team (SYKE, ISRIC, CIHEAM-Bari), in consultation with the local partners and stakeholders. The aim of the toolbox is to simulate the effect of selected BMPs (Best Management Practices) on environmental and socio-economic indicators for each of the study locations. During various workshops (in Wageningen, NL, Helsinki, Finland and Turin, Italy) and subsequent online meetings, the modelling partners together developed the toolbox.

This report describes the steps taken by the modelling team: first, potential models were discussed (section 2) in relation to the BMPs selected by the local partners as well as which indicators were relevant to be simulated for the challenges encountered in each case study. Then, the most suitable models were selected (section 3). Subsequently, a coupling approach was discussed and implemented by SYKE (section 4). Meanwhile, the functionality of the toolbox was discussed, including an approach to post-process some of the direct output of the coupled model further into relevant socio-economic indicators (section 5 and 6). Finally, a potential interface set-up is outlined (section 7).

1. Introduction

1.1 Background

Within the WATDEV project, the aim is to simulate the possible impact of scenarios due to the upscale and out-scale of BMPs and Innovations from areas of implementation to large scale/catchment within the study areas and possibly beyond them. For this aim, a toolbox is developed, and relevant and interesting scenarios are co-developed in collaboration with the stakeholders and local partners. The toolbox consists of a set of interlinked models. Such a toolbox allows simulated thematic scenarios looking at the impact of selected BMPs on water productivity, water, and groundwater resources yield and quality, soil quality and erosion, environmental sustainability, socio-economics, ecosystem services and hydrology. Models will be selected on the base of their degree of suitability within the East African context and conditions, and on the base of their successful use in similar conditions. A set of models (already used) will be made available by CIHEAM Bari, ISRIC and SYKE based on their modelling expertise. The choice to use a specific model of the combination of two or more models depends on the type of best practice/innovation/solutions and their focus.

The modelling team (SYKE, ISRIC, CIHEAM-Bari) has organized several workshops and online meetings to discuss various aspects of the toolbox, ranging from discussing and presenting existing potential models to be included in the toolbox, to model selection in relation to the selected BMPs and challenges encountered in the study areas, as well as the coupling of the selected models and a post-processing socio-economic part of the toolbox.

This report presents the results of these discussions and developments within WATDEV project.

1.2 Objectives of the Modelling Strategy

1.2.1 Overall Objective

The overall objective was to determine a modeling strategy with selected models and model combinations defined.

1.2.2 Specific Activities

Several specific activities were outlined to reach this objective as part of activity A3.1. The activities relevant for the overall objective outlined above include:

i) Review inventory of BMPs and identification of existing models suited to simulating BMPs impact
ii) Review survey of stakeholder scenario perspectives and indicators (see D3.1.2)
iii) Technical workshops to select models and model combinations
iv) Work on individual models/modules to capture impacts of BMPs and integration of models for multi-thematic modelling

1.3 Outline

This report will present the following topics: (1) short overview of the models that were originally considered to be potentially included in the modelling strategy; (2) Description of the models that were selected to be included in the modelling strategy; (3) the approach that was followed to couple these models; (4) overview of which indices the coupled model can deliver either directly or with post-processing steps; (5) overview of the post-processing steps to be included in the toolbox; and (6) a tentative presentation of how the model could eventually look like.

2. Initial models and model selection

2.1. Models initially considered

The modelling working group, consisting of SYKE, CIHEAM and ISRIC partners, organised a first workshop on 11-12 October 2022, in Wageningen, The Netherlands, hosted by ISRIC. The goal of this workshop was (1) to discuss potential models versus BMPs for each study area and (2) to draft a first agreement on the models to be used.

First, the processes, problems and BMPs in each study area were briefly reviewed, as far as the information was available. Then, several models that the partners have experience with (see Table 1) were briefly presented.

Table 1 - Overview of candidate models

SYKE	ISRIC	CIHEAM
WSFS	PESERA	DSSAT
VEMALA	LISEM	
INCA	QUEFTS-DESMICE	
Yasso	SWAT	
Coherens	MMF - SE	

It was then decided that more detailed model requirements were to be gathered and put into an overview table. The toolbox outline was also discussed, as well as whether the same model(s) would be considered for all study sites or whether different model combinations would be used.

2.2. Model selection

Model selection was made from an initial list of models that the experts considered as potentially useful for the project, as described in the previous section. The selection aimed at models that can simulate the most important processes in each study area, including the Best Management Practices (BMPs) under consideration by the stakeholders; and provide results for the associated Key Performance Indicators (KPI) for BMP performance. A secondary objective was to select models with which the stakeholders had some familiarity.

The first step in this process was to conduct a series of online bilateral meetings with the partners of each study site, in March and April 2023. The type of BMPs selected for each study site are shown in Table 2. While some BMPs overlapped, it is interesting to note that all local partners selected a Water Users Association, but each partner had a different understanding of what the management priority of such association should be, leading to different implementations of each measure.

In any case, it was clear from this list that the selected models should be able to simulate:

- interactions between permanent and annual crops;
- complex agricultural practices, such as crop rotation and fertilization with different fertilizers;
- different cultivars (improved seeds) for the same crop;
- irrigation impacts on crop growth;

- water supply amounts.

Moreover, the simulation of detailed crop calendars and irrigation schedules requires a daily time-step, while the simulation of the water supply requires a model which can be applied outside the irrigation area, to include water sources from which irrigation water is abstracted.

Table 2 - Best Management Practices to be simulated in each case study, according to local partners.

Best Management Practice	Egypt	Ethiopia	Kenya	Sudan
Intercropping trees and crops / agroforestry	X	X	X	
Improved crops (rotation / improved seeds)		X		X
Improved fertilization (manuring)	X			
WUA priority: manage crop selection				X
WUA priority: manage water resource use	X			
WUA priority: manage irrigation schedule		X	X	

WUA: Water Users Association

These meetings also determine what would be the KPIs with which the BMPs should be assessed; the results are shown in Table 3.

All partners are concerned with soil quality, but a contrast between study sites is visible: while the Ethiopia and Kenya partners are concerned with surface processes (water quality, soil erosion), the Egypt partners are concerned with groundwater. This is due to the nature of the study areas, since the Nile Delta is flat and has little rainfall, making surface processes less relevant than in the other study areas. From these results, it was clear that the selected models should be able to simulate:

- soil processes, including organic matter and nutrient cycles;
- vegetation growth and productivity;
- hydrological processes and water balance;
- soil erosion and nutrient mobilization and transport to surface waters;
- groundwater processes, including nutrients;
- salinity.

Table 3 - Key Performance Indicators to assess the BMPs in each case study, according to local partners.

Key Performance Indicator	Egypt	Ethiopia	Kenya	Sudan
Water balance		X	X	
Water quality (contamination, salinity)		X	X	
Soil quality (OM, nutrient, structure)	X	X	X	
Productivity		X	X	
Soil erosion		X	X	
Groundwater quality (contamination, salinity)	X			

These results were discussed during a modelling workshop in Helsinki during April 2023. **Error! Reference source not found.** shows the available models, organized by the spatial scale at which they operate. One thing that stands out from the figure is that the SWAT model is the only one mentioned by both the modelling experts and the local partners; this made it a better candidate than similar alternative models due to already existing expertise and familiarity. Another thing that stands out is that there are several alternative models operating at the watershed scale, but a much smaller selection focusing on the field scale or directly on crops and species.

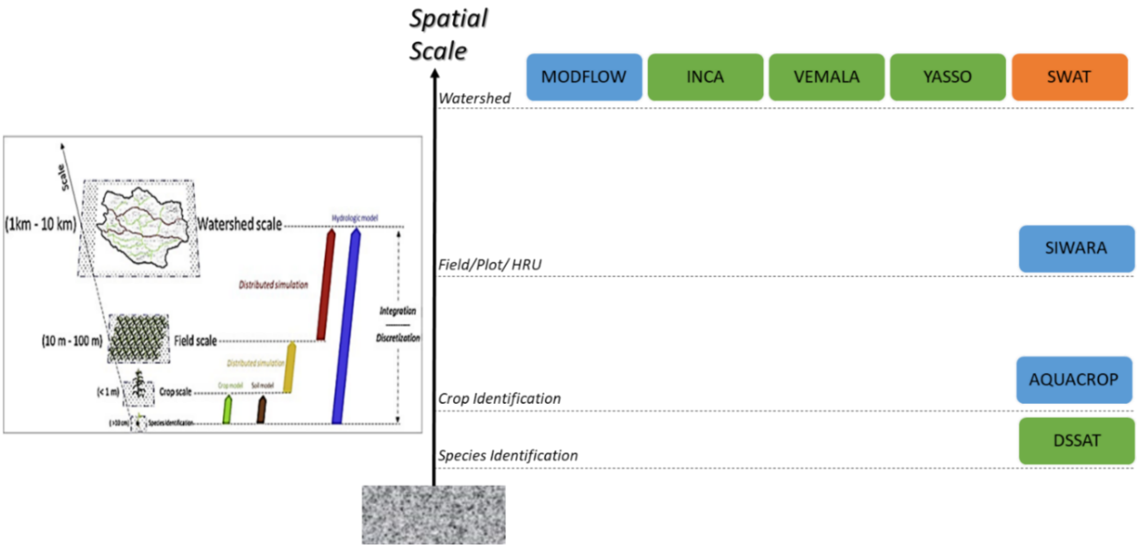

Figure 1 - Available models according to spatial scale. Green: models suggested by experts; blue: models suggested by local partners; orange: models suggested by both experts and local partners.

After the Helsinki workshop, a modelling taskforce including elements from SYKE, ISRIC and CIHEAM was set up to discuss which models to integrate in the tool, and how to do it. Comparing the BMPs, KPIs and available models at different spatial scales, some requirements for the models which would be used in the project were determined:

- at the watershed scale, models able to represent both surface and groundwater quantity and quality were required, including the impacts of irrigation water demand;
- the detailed nature of some agronomic BMPs required a model able to represent vegetation and soil processes, including the link between crop production and soil water and nutrients.

A final proposal was submitted for discussion during a subsequent modelling workshop in Turin in October 2023. The SWAT model was considered the most appropriate for the project, given its capacity to simulate all the required water, vegetation and soil processes at the watershed scale with a daily time-step, the familiarity of some local partners with the model, and also the strong international development community supporting the model. Another advantage was the existence of a coupled SWAT-MODFLOW version, which was able to simulate groundwater processes with the detail required by the Egypt case study. However, while SWAT-MODFLOW is able to simulate vegetation and nutrient processes, it was decided that the detail was insufficient to assess the BMPs proposed for the study sites. This led to the decision of coupling this with the DSSAT model for an improved simulation of crop growth and soil processes in the root zone. The relevant processes and the role of each model is illustrated in

Figure 2.

Some local partners suggested the inclusion of a hydraulic model to the tool, in order to better simulate issues related with irrigation water distribution. However, it was felt that this would go beyond the scope of the project and create an unnecessarily complex tool. It is also important to note that these models have limited capacity to simulate the interaction between trees and annual crops and also don't include well-developed salinity processes. It was decided to explore if such processes could be added to the models later on.

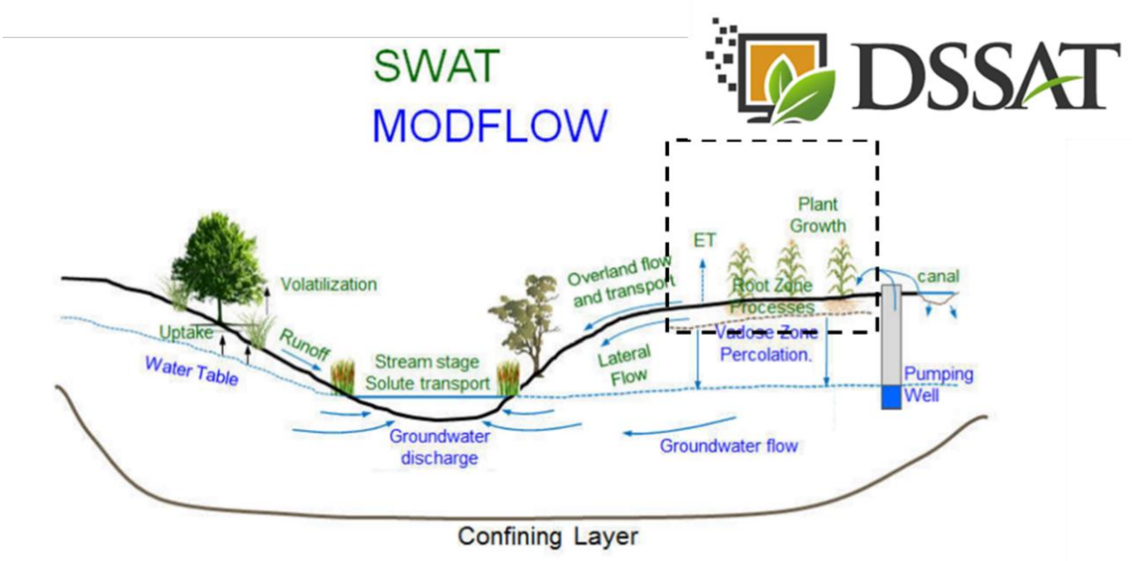

Figure 2 - Selected models and their interactions.
Green = SWAT; blue = MODFLOW; and DSSAT is represented by the dashed box.

3. Description of selected models

3.1. SWAT

The Soil & Water Assessment Tool (SWAT) is a widely used watershed-scale model (Zhao et al., 2024). It is able to simulate the flows of surface and groundwater, as well as vegetation development, soil erosion, nutrient soil processes and mobilization, and water quality. For irrigation, the model can simulate both effects on crops and on water sources such as reservoirs or groundwater.

The main processes are shown in in

Figure 2 (green); there is extensive documentation on the project website (https://swat.tamu.edu/). SWAT is free to use and open-source and has a very large community of model users and developers; it is used all over the world to assess processes in the nexus between water, soil, and food production, including irrigation, soil degradation, non-point source pollution, and regional water management (Zhao et al., 2024).

The model is semi-distributed in space; it subdivides the simulation area into Hydrological Response Units, which are unique combination of land use, soil type and slope within a given sub-watershed (

Figure 3). The selected version was SWAT2012, and not the more recent SWAT+, due to the existence of a SWAT-MODFLOW coupled version with improved description of groundwater (Bailey et al., 2016; see also technical information in https://swat.tamu.edu/software/swat-modflow/ and the next section).

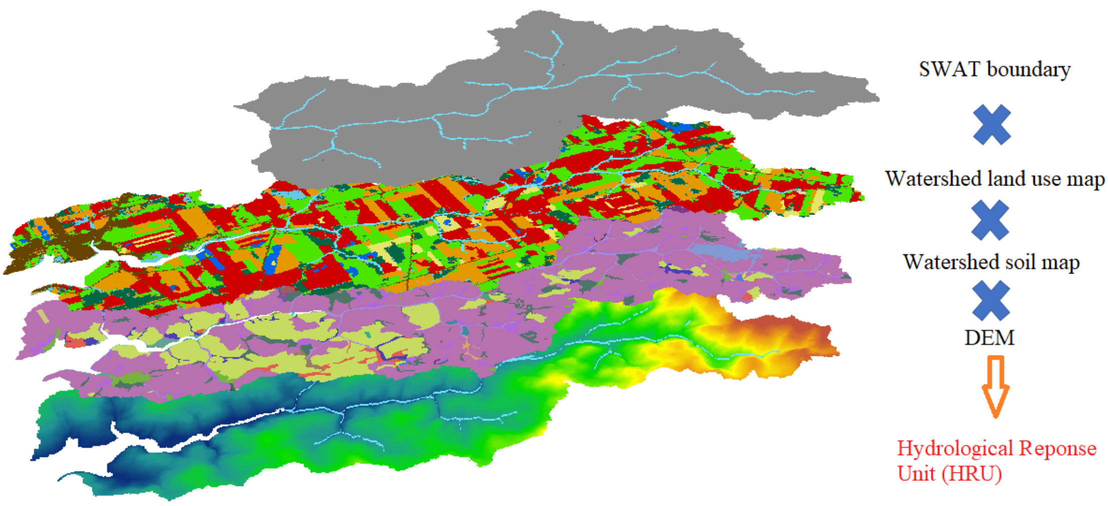

Figure 3 - Hydrological Response Units in SWAT
(source: ESRI https://ecce.esri.ca/blog/unb-blog/2019/12/04/identifying-source-of-nitrate-load-using-swat/).

3.2. MODFLOW

MODFLOW was developed by the U.S. Geological Survey to simulate groundwater flow through aquifers. It is a free, open-source model with a modular nature, allowing the simulation of different processes (Langevin et al., 2017). The model can be considered as a de-facto standard for aquifer simulation, and has extensive documentation available (https://www.usgs.gov/software/modflow-6-usgs-modular-hydrologic-model). The main processes are shown in

Figure 2 (blue).

MODFLOW simulates the modelling domain as a 3-D grid (Figure 4). This poses some difficulties in coupling it with the HRU nature of SWAT. A solution was already provided in the form of a SWAT-MODFLOW coupling (Bailey et al., 2016), where both models are linked by disaggregating the HRUs according to the underlying MODFLOW grid to simulate flows from SWAT to MODFLOW and vice-versa. The SWAT-MODFLOW coupling simplifies the implementation of the modelling tool.

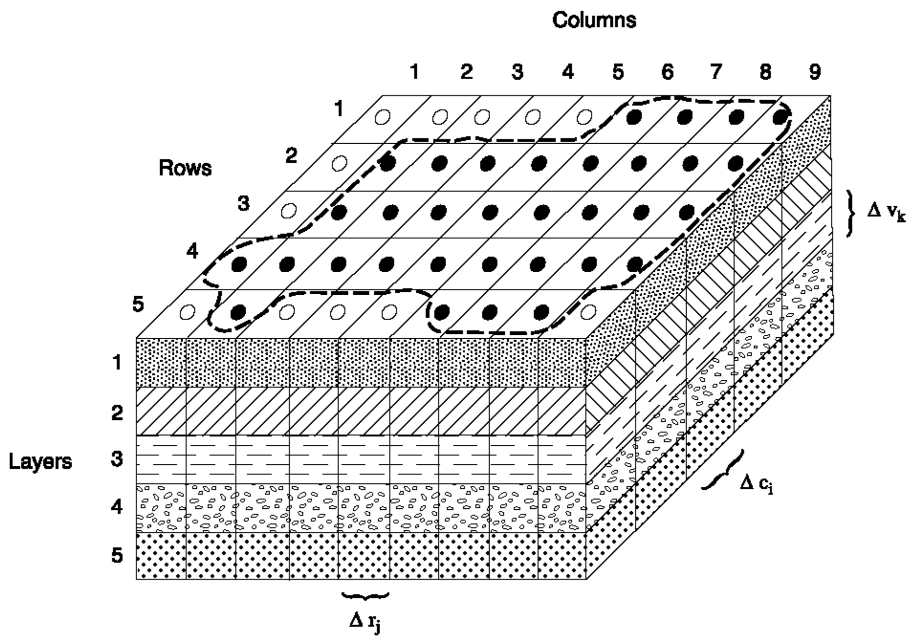

Figure 4 - 3-D simulation grid in MODFLOW (source: USGS - https://pubs.usgs.gov/tm/2005/tm6A16/).

3.3. DSSAT

The Decision Support System for Agrotechnology Transfer (DSSAT) is a freely available open-source model, focusing on simulating crop growth and development, and related processes in the root zone (Hoogenboom et al., 2019). The model is well documented online (https://dssat.net/).

The main processes can be seen in

Figure 2; they include plant development, soil-plant-atmosphere water flows, soil water, carbon and nutrient dynamics, and crop management (e.g. fertilization and irrigation).

The use of detailed crop growth models allows the user to simulate different cultivars with a great level of detail. The model operates at a point scale, i.e. representing a single plot in a field; it can therefore be linked with SWAT-MODFLOW to create representative simulations for areas with a certain land use, as evidenced by previous SWAT-DSSAT couplings (Malik et al., 2020).

4. Model coupling approach

After selecting the models that will be used in the toolbox, the modelling task force made an initial selection of the features that are taken from each model, like perennials from SWAT, others from DSSAT (if included in the CROPGROW submodule). The main idea of the model coupling is to maintain as much as we can from the SWAT side since it includes by default the spatial aspect of the model needed.

In the modelling workshop in Helsinki (April 2023) existing modelling coupling approaches were presented (Figure 5). As indicated in Figure 5 only embedded coupling or integrated coupling approaches were suitable for WATDEV purposes. Reasons for neglecting some approaches are the fact that crop grow rate and water flow/amount is coupled to each other rejects sequential, loose, graphical interface and shared data coupling from the possible coupling schemes.

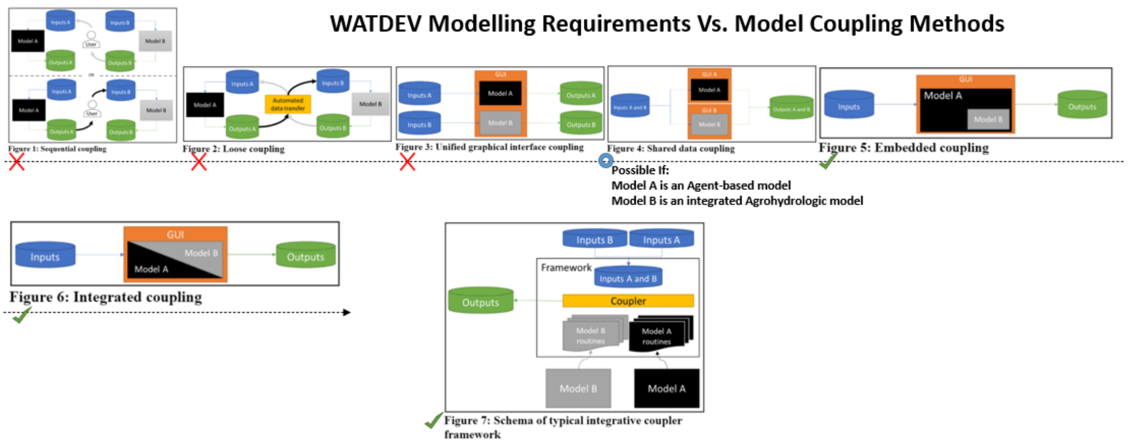

Figure 5 - Available model coupling schemes.

In a later discussion it was realised that embedded coupling would lead to a program that is hard to update and/or modify. Thus, the selected integration framework for the WATDEV purposes was integrated coupling with an interface between the DSSAT and SWAT-MODFLOW models as presented in the Modelling workshop meeting in Turin in October 2023.

Selected SWAT-MODFLOW codes are a part of the greater SMRT-package that includes source codes for SWAT, MODLOW and rt3D. The interface connecting those three individual models is called SMRT. Model rt3D is for moving substances in groundwater.

The chosen integration approach is similar and consistent with an existing one (SMRT).

Using an interface between different models (see Figure 6) make maintenance and modification of the integrated model more flexible and easier and it requires a minimal amount of changes to the original source codes for both of the original models.

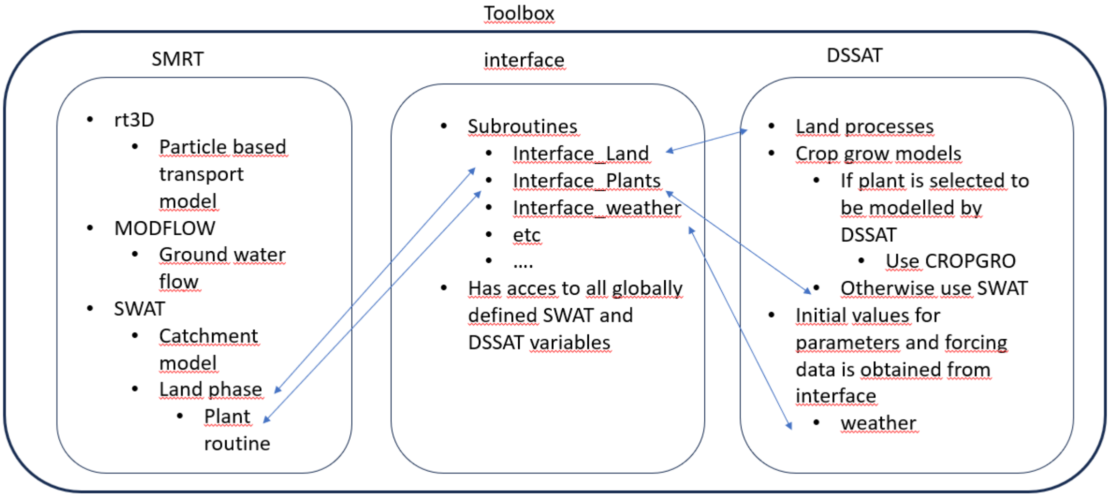

Figure 6 - Chosen coupling scheme with interface

In addition, using an integrated approach via an interface, makes it possible to end users to select which features are used from which model.

However, it should be noted that even though some functionality of the coupled model is possible it has not been implemented for the first version of the coupled model.

5. Modelled indicators

During various online meetings of the modelling and toolbox group, the different indicators that the toolbox should be able to produce output on were discussed.

The following list (Table 4) was compiled in which it was indicated which indicator is directly modelled (DM) by coupled models in the toolbox and which indicators would need to be calculated in a post-processing (PP) step in the toolbox.

Note that not all indicators selected by the various local workshops are included, as some of them cannot be modelled either directly or using post-processing.

Table 4 - Indicators simulated by the coupled model, either directly (DM) or by post-processing (PP)

SECTORS	OBJECTIVES	indicators	Feasibility (DM/PP)
Economy	1. Make farm costs manageable.	• **Crop Yield (Tons/Ha)** • **Benefit-cost ratio of production** • **Price-Cost Ratio (compares selling price to cost of production)** • **Cost saving (US$) as a result of BMP adoption**	DM PP PP PP
	2. Increase crop production.	• **Crop yield (total production (Kg)/Total land area (ha)**	DM
	3. Increase farmer's income.	• **Total household Net farm income (GFI- Total production costs & expenses)** • **% increase in net farm income**	PP PP
Groundwater	4. Avoid groundwater pollution.	• **Level of Nitrate content of groundwater**	DM
	5. Enhance water quality.	• **Level of water salinity (standard methods)**	DM
	6. Ensure suitable groundwater access.	• **Intensity of water use by agriculture: Amount of irrigation water (mc) used per unit of cropped land (ha)** • **Technical efficiency (mc) and economic efficiency (€) in water use** • **Depth to groundwater (m) (ground water at much lower depths is more preferred and accessed because of low salinity")**	DM PP PP
Soil	7. Prevent soil erosion.	• Area affected by soil erosion (%, Km^2): **Proportion of the area affected by soil erosion (%)** • Amount of soil washed away by runoff: **Average soil loss ($t\ ha^{-1}\ yr^{-1}$)**	DM DM
	8. Maintain soil health	• **Soil Organic Carbon ($t\ ha^{-1}$)**	DM
	9. To help crops grow better.	• **Soil fertility (SOM, N, P_2O_5, K_2O)**	DM
Crop	10. To make crops productive.	• **Production yield of crop per unit of cultivated area ($t\ ha^{-1}$)**	DM
	11. To make crops healthier.	• **Nutrient (N, P) use efficiency (kg product/kg N, P)**	PP
Surface water	12. Avoid surface water pollution.	• **Level of Nitrate content of surface water**	DM
	13. To enhance water quality.	• **Level of water salinity (standard methods)**	DM
	14. Keep water flow safe.	• **Annual floods frequency (exceeding a certain threshold)** • **Proportion of land prone to flood risks (%)**	PP PP

SECTORS	OBJECTIVES	indicators	Feasibility (DM/PP)
Atmosphere	15. Minimize greenhouse gases emissions.	• **GHG emissions per ha/yr**	DM
	16. Make the air cleaner.	• **Carbon storage and sequestration in the crop (t CO_2 ha^{-1})**	PP

6. Post-processing approach

After integrating DSSAT and SWAT-MODFLOW, the post-processing step involves computing additional indicators that are not directly generated by the integrated model (see section 5).

Since some of the indicators selected by stakeholders require external or derived calculations, we must design a systematic post-processing workflow. This process includes:

a) **Data Extraction and Harmonization:**

- Extract relevant outputs from DSSAT (e.g., crop yields, nitrogen uptake, water use efficiency) and SWAT-MODFLOW (e.g., groundwater levels, streamflow, soil moisture).
- Convert outputs into a common spatial and temporal resolution for consistency across datasets.

b) **Indicator-Specific Computation:**

- Identify the indicators and the required input variables. This step is summarized in Table 5.
- Develop or adapt algorithms to compute these indicators within the Toolbox, and automate their calculations.
  - **Economic indicators** (e.g., net farmer income, cost-benefit ratios) require combining model outputs with cost and price data.
  - **Environmental indicators** (e.g., nutrient leaching, **Carbon sequestration, amount of fertilizer/pesticides, etc.**) may need spatial aggregation or empirical formulas based on model outputs.

c) **Validation and Sensitivity Analysis:**

- Compare computed indicators with observed data or literature values to verify accuracy.

Table 5 provides a brief definition of the post-processing indicators, and their required input variables. The star indicates that this input variable is the output of the integrated model.

We selected **WOCAT (World Overview of Conservation Approaches and Technologies)** as a data source for economic and social indicators because it provides a globally recognized and standardized database of Best Management Practices (BMPs) related to land and water management. WOCAT offers comprehensive economic data essential for our analysis, including discount rates, BMP lifetime, and the economic value of BMP benefits. Additionally, it provides detailed financial information such as capital (CAPEX) and operational (OPEX) expenditures, as well as cost comparisons before and after BMP implementation. This includes the cost of cultivation and selling prices of products post-BMP adoption, enabling a thorough assessment of cost-effectiveness and profitability. WOCAT's dataset is built on field-based case studies contributed by practitioners and researchers, ensuring reliability and relevance to real-world conditions. Furthermore, its alignment with sustainable development goals (SDGs) and focus on evidence-based decision-making make it an ideal source for assessing both the financial feasibility and broader socio-economic impacts of BMPs. Integrating WOCAT data into our post-processing step enhances the accuracy and applicability of our economic and social indicators, supporting informed decision-making for sustainable land and water management.

Table 5 - Definition of post-processing (PP) indicators

Sub-sector	Indicator Number	Definition	Input variables
Economic Indicators	**10.2**	Benefit-cost ratio of BMP of production Calculated as the ratio between the discounted economic value of all benefits generated by implementing the BMP and the discounted costs to implement the BMP	• Discount rate • Lifetime of BMP • economic value of benefits of BMP • CAPEX and OPEX of BMP
	10.3	Price-Cost Ratio Calculated as a ratio between the selling price and the cost of production for each product in each HRU	• selling price for each product after BMP • cost of cultivation for each product after BMP
	10.4	Cost saving (US$) as a result of BMP adoption Calculated as the difference in cost of cultivation before and after the BMP implementation	• cost of cultivation before the BMP • cost of cultivation after the BMP
	12.1	Total household Net farm income Calculated as Gross Farm Income- Total production costs & expenses	• yields after BMP* • selling price for each product after BMP • cost of cultivation of each product after BMP
	12.2	Percentage increment in net farm income Calculated as the diffeerence in the net farm income = income-cost before and after the BMP implementation	• yields before BMP Implementation* • selling price for each product before BMP • cost of cultivation of each products BMP
Social indicators	**12.3**	Labour use Calculated as the sum of crop-specific labour requirement (in hours/ha) by their corresponding cultivated area	• crop-specific labour requirement (in hours/ha) • cultivated area per crop*
Environmental indicators	**15.2**	Technical efficiency and economic efficiency in water use Calculated as the amount of water required (mc) for each unit produced ($)	• amount of water required (mc/ha) per crop after BMP* • yields after BMP* • selling price for each product after BMP
	26.1	Carbon sequestration	• crop-specific sequestration factors after BMP* • cultivated area per crop*

* This parameter is a direct output of the integrated model

Sub-sector	Indicator Number	Definition	Input variables
		Calculated by the multiplication of crop-specific sequestration factors by their corresponding cultivated area	
Crop	**20.1 PP**	Amount of fertilizers/pesticides per unit of crop (Residues level in the product): Calculated as the ratio of the total amount of of fertilizers/pesticides per the total crop yield.	• Total Amount of Fertilizers/Pesticides Applied* • Total Crop Yield*
Groundwater	**15.1 PP**	Intensity of water use by agriculture: Calculated as the amount of irrigation water (mc) used per unit of cropped land (ha)	• Total Water Use for Agriculture* • Agricultural Area*
	15.2 PP	Technical efficiency (mc) in water use: Calculated as the ratio of agricultural output produced per unit of water used.	• Crop yield data* • The sum of surface water and groundwater used for irrigation*
	15.2 PP	Economic efficiency (€) in water use: Calculated as the ratio the monetary value of the agricultural output produced per unit of water used.	• Crop yield data* • Market price • The sum of surface water and groundwater used for irrigation*
	15.4 PP	Depth to groundwater (m) (ground water at much lower depths is more preferred and accessed because of low salinity"): The depth to groundwater (D_gw) is measured in meters and can be directly obtained from the SWAT-MODFLOW model. The depth to groundwater = Ground surface elevation − Water table elevation	• Ground surface elevation* • Water table elevation*
	15.5 PP	No. of community members with access to water rights or secure water resource allocations:	• Socio-economic and legal data
Atmosphere	**26.2 PP**	*Carbon storage and sequestration in the crop:* Refer to the amount of carbon dioxide (CO_2) captured and stored by crops through the process of photosynthesis	• Carbon sequestration • Area of the crop *
	26.3 PP	Air Quality Index (AQI): The Air Quality Index (AQI) is a standardized indicator that communicates the level of air pollution and its potential health impacts	• Pollutant concentration • The breakpoints closest to the measured concentration

* This parameter is a direct output of the integrated model

7. Toolbox visualisation

During the regular meetings of the toolbox development team a schematic version of the WATDEV toolbox was also discussed that would address end-user needs while remaining user-friendly and accessible to all parties. This schematic overview was presented at the second stakeholder forum meeting in May 2024 to gather feedback for further development and modifications.

The toolbox consists of two essential components: an integrated model (SWAT-MODFLOW-DSSAT, see sections 3 and 4) and a post-processing tool (see section 6). It can also incorporate additional models, such as hydraulic models or an optimization tool, if required by the stakeholders (Figure 7). The toolbox can be used to simulate water demand under various scenarios; assess erosion, water and soil quality; implement Best Management Practices (BMPs); and analyse the cost-effectiveness of different scenarios.

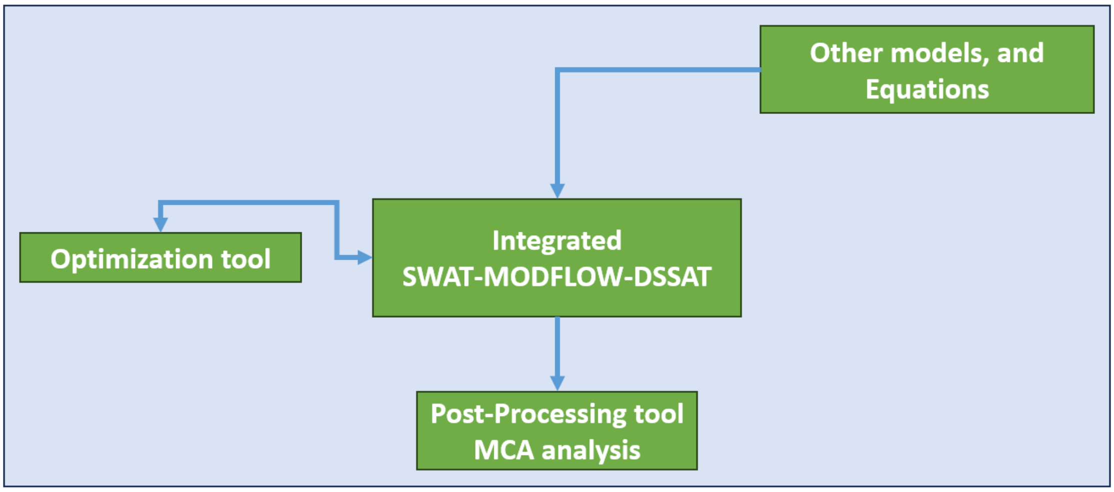

Figure 7 - Schematic overview of toolbox components

The toolbox will allow users to provide relevant data for model simulation and post-processing through its user interface (Figure 8). User inputs include:

- **Study area/watershed**
- **Preference for using (or not using) the integrated model**
- **Selection of relevant indicators**
- **Crop management data** (e.g., crop rotation, replacement, agroforestry)
- **Crop prices and yields**
- **Measure prices** (e.g., drip irrigation)

The simulation process begins by specifying the simulation time period and determining the time step for output results. Users can then choose from a list of predefined scenarios or define a custom scenario (e.g., combining different interventions of one Best Management Practice (BMP) or multiple BMPs).

A post-processing tool will allow users to compare different management options using a multicriteria analysis approach. Due to the complexity of water resource management, the toolbox is not designed for universal optimization by all users. Instead, if needed, an optimization feature will be developed specifically for regional or large-scale planning, to be used by local authorities. This optimization tool could provide spatially optimized BMP interventions based on specific objectives (e.g., maximizing yield, minimizing costs, or reducing water consumption and erosion).

Results from different scenarios can be viewed in various formats, including map-based outputs, charts, graphs, and downloadable time series. The toolbox will be accessible through a web-based platform, available on any standard web browser.

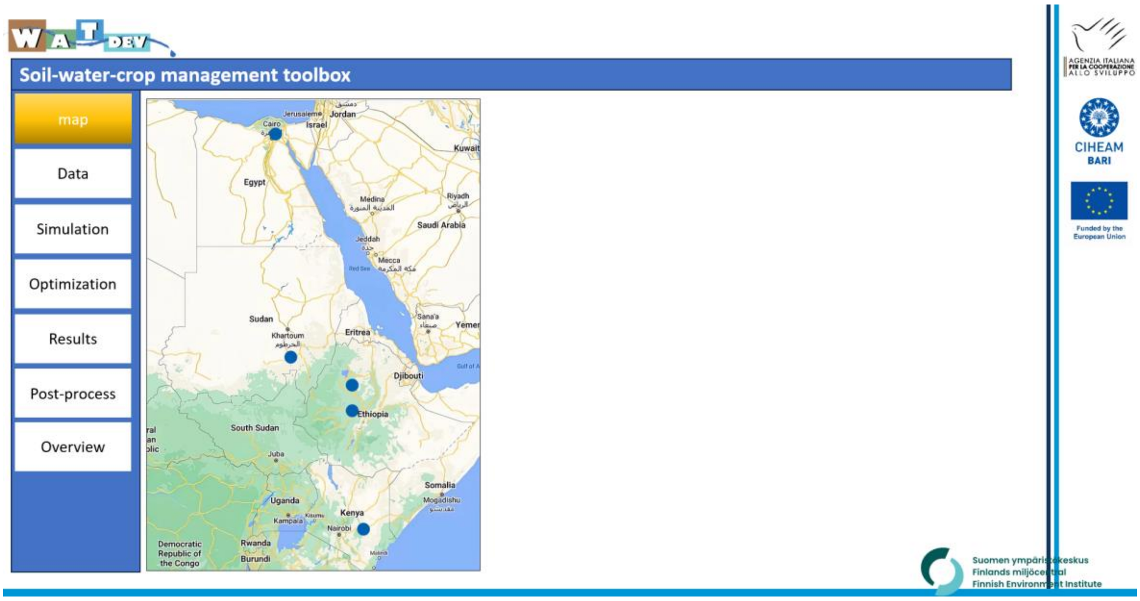

Figure 8 - Example of potential user-interface of the WATDEV toolbox

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