NPP-SOL
Non-Point Pollution Solutions

This project is part of the PRIMA programme supported by the European Union

PRIMA-SECTION 2-2022

"Modelling and Technological Tools to Prevent Surface and Ground-Water Bodies from Agricultural Non-Point Source Pollution Under Mediterranean Conditions"

NPP-SOL

Report with the description of physical and bioeconomic strategy, concepts and scenarios adopted to build operational MT integrating DAHBSIM and FLOWS models (M14)

Deliverable number: D1.2

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PRIMA Partnership for Research and Innovation in the Mediterranean Area

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1. Introduction

NPP-SOL strategy mostly relies on two main principles: 1) *attenuation* and 2) *interception* of agricultural pollutants fluxes before they reach the water bodies (Figure 1). Attenuation has to mainly be obtained by Site-Specific Best Management Practices (SSBMP) whereas interception is assigned to PPTs. In practice, by analyzing different alternative scenarios, the MT will identify the best management options of water and agro-chemicals (timing, quantities, application splitting), as well as of agronomic practices (tillage, crop rotations, organic matter content) to minimize the pollutant mass into water leaving agricultural fields and flowing to the surface and groundwater bodies, still maintaining profitable farmer activities. PPT will thus finalize the abatement of the pollutants already attenuated by the SSBMP.

In this sense, SSBMP and PPT are not thought to work independently but rather in a **virtuous sequence** where SSBMP will look for minimizing the pollutant loads to be treated by PPT. SSBMP will be strictly related to the case studies (CS), so that the same PPT could require different BMP depending on the physical context where PPT have to be developed.

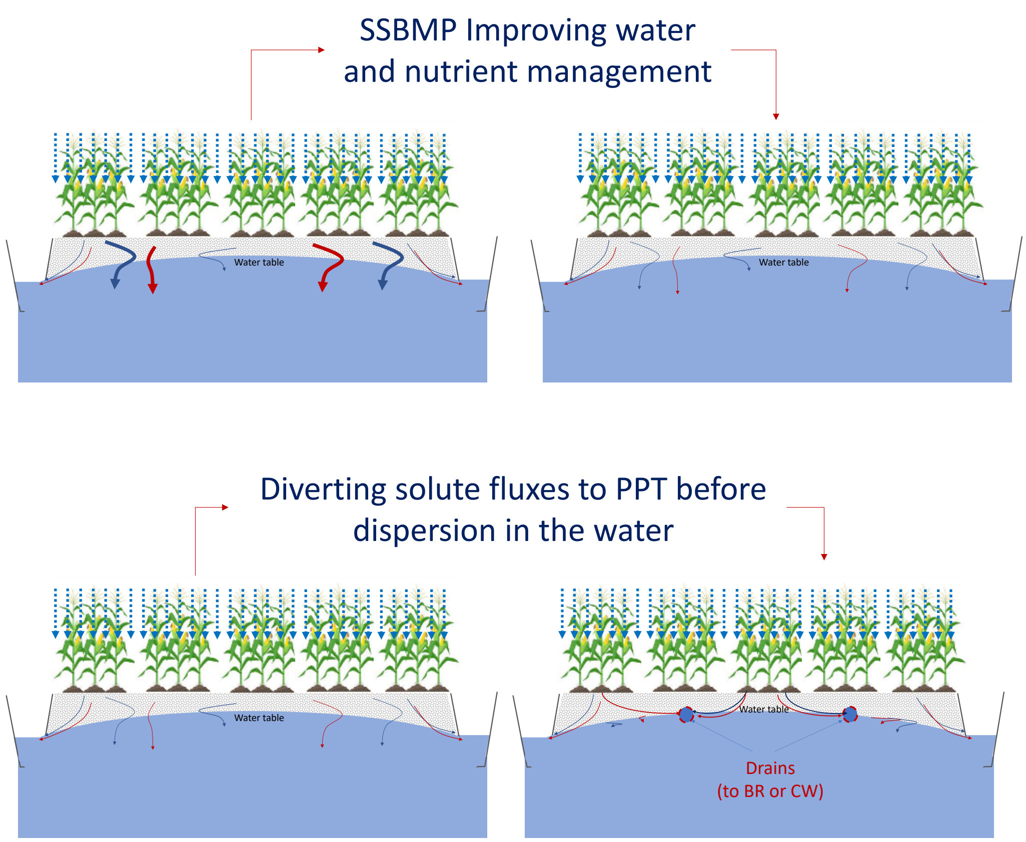


*Figure 1. Schematic view of the improved management scenarios**

**The upper graph represents the attenuation by improving water and nutrient management. The lower graph represents interception by artificial drainage to intercept water and nutrients before reaching groundwater.*

<u>This document presents the strategy followed by the NPP-SOL project to establish different management scenarios to address the needs of **attenuating non-point source pollutant fluxes to water bodies**. The</u>

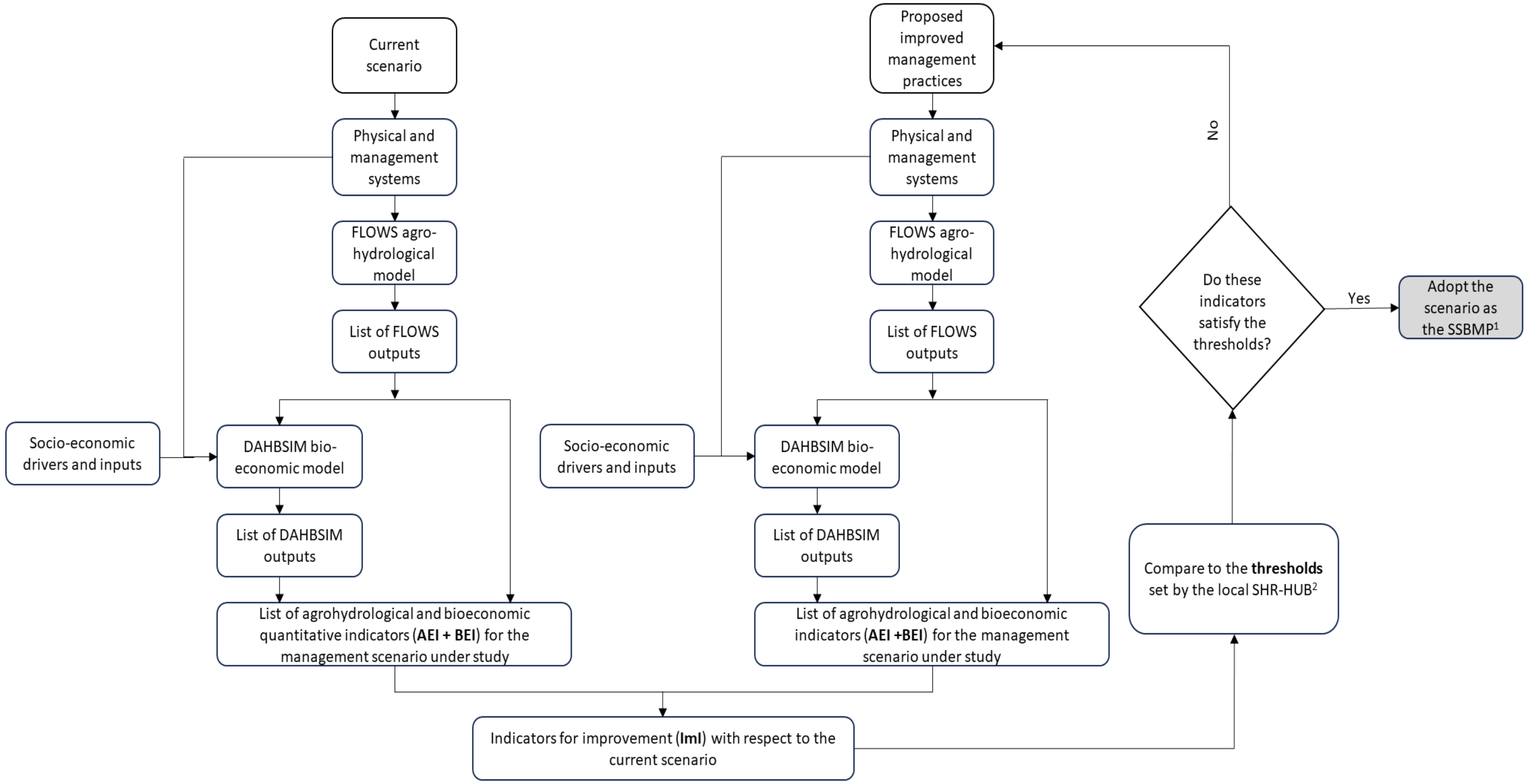
document, hence, illustrates how the modelling tools, MT, coupling physical (FLOWS) and bioeconomic (DAHBSIM) models, will be used throughout the project to analyse and evaluate alternative management scenario, with the final aim to identify SSBMP able to attenuate agricultural pollutants fluxes to water bodies.

Finding the SSBMP starts by analysing the current scenario by collecting data on the management and physical systems, as part of the WP3. These data will be used as inputs, first, to the agrohydrological model FLOWS. Thus, part of the FLOWS outputs, along with specific socio-economics driver and inputs, will be used as inputs to the bioeconomic model DAHBSIM. The outputs of the two models will be used to deduce a group of quantitative agro-environmental, **AEI**, and bioeconomic, **BEI**, indicators, i.e., the amount of nitrate leaching to groundwater, farm income, etc. Following the current scenario, alternative scenarios will be proposed for each case study by the researchers. The proposed scenarios will mostly change the management systems, trying to optimise the irrigation water and nutrient management, to reduce nutrients leaching to water bodies and improve irrigation efficiency by optimising irrigation volumes. Thus, the MT will be used to evaluate these new scenarios by obtaining new AEI and BEI. After the current scenario, i.e., the baseline scenario, other scenarios will be created and proposed by the researchers.

The degree of improvement with respect to the current scenario will be evaluated by a new set of indicators, calculated as percentage ratios of the AEI and BEI obtained under the current scenario to the AEI and BEI obtained under the alternative scenario. These indicators for improvement, **ImI**, will include, as examples, the percentage change in farm income or the percentage change in the nitrate leaching to the groundwater with respect to the current scenario.

Specific thresholds will be developed by local SHR-HUBs for each indicator to establish when the ImI obtained for a given scenario may be considered acceptable. Only then, the management scenario under analysis will be added to the list of SSBMP candidates. In turn, these will be again proposed to the SHR-HUBs for final approval. All this iterative procedure is schematically illustrated in Figure 2.

Figure 2 summarizes the strategy followed to use the MT and concepts followed to build different management scenarios and iteratively select the Site-Specific Best Management Practices, SSBMP, using operational FLOWS and DAHBSIM models. The following sections provide details on the various blocks involved in the figure.



1. SSBMP: Site-Specific Best Management Practices
2. SHR-HUB: Stakeholders and Researchers' Hub

Figure 2. Schematic view of the strategy and concepts followed to build different management scenarios and select the SSBMP using operational FLOWS and DAHBSIM integration MT

2. Physical and management systems

Defining the physical and management systems aims at defining the input files for the MT for each case study. Deliverables D4.1(FLOWS software and related handbook), D4.2 (DAHBSIM software and related handbook) and D4.3 (Integrated NPP-SOL MT software and related handbook) explain in detail the MT and the related inputs. Building the input databases describing the physical and management systems fall within the work package WP3. For this purpose, the databases required to be collected from each case study to describe the physical system were created as spreadsheets that were shared with all the partners. A series of meetings was carried out with each Case Study (CS) partners to explain and discuss these databases.

In addition, MSc students from CIHEAM-IAMM carried out internships in the Italian and Spanish CSs to collect some of the bioeconomic farm household data needed. The Figure 3 provides some examples of the different excel sheets adopted for building the databases.

Specific site data to run the FLOWS Model_To fill for the experimental site for the implementation of the bioreactor/c. wetland

profile classification								hydrological properties						
Antrosol		horizons	horizon depth	texture			bulk density	sat.Wat.Cont.	air entry point	slope	sat.Hydr.Cond	field capacity	wilting point	dispersivity
	symbol		z	sand	silt	clay	ρb	θs	alfaVG	nVG	Ks	fc	wp	λ
	units		cm	%	%	%	g/cm3	cm3/cm3	1/cm		cm/d	cm3/cm3	cm3/cm3	cm
		Ap	40	94.8	2.7	2.4	1.67	0.361	0.033	1.190	118.1	0.235	0.125	2.000
		C	60	96.1	0.8	3.1	1.74	0.316	0.033	1.190	429.4	0.217	0.131	2.000
		Ab	100	96.7	1.2	2.1	1.78	0.309	0.033	1.190	480.0	0.213	0.129	2.000
		C'	140	95.7	0.3	4.1	1.83	0.298	0.033	1.190	360.8	0.207	0.127	2.000

Figure 3. A screenshot of an example of the database spreadsheet used to describe a study area and as an input for the MT

3. Socio-Economics drivers and inputs

The farming system faces many uncertainties and is affected by various external and internal drivers. External and internal drivers shape agricultural practices and outcomes. Internal drivers are the drivers that are related to the decisions of farmers however external drivers are beyond the direct control of farmers and impact their decisions (Lead et al., 2005). Therefore, it is important to identify the key drivers affecting the farm system.

This list of selected internal and external drivers in the NPP-SOL project is given in Table 1. These drivers will be considered possible shocks for testing the resilience of the system.

Among the external drivers that will affect farmers' decisions and agricultural practices, are climate change from environmental conditions (Fanzo & Davis, 2021), market prices (Yang & Ju, 2014) from market factors and government policies and EU regulations from policy (Yang & Ju, 2014) were selected.

Among the internal drivers, such as crop rotation, irrigation techniques, and tillage methods, which play an important role in farmers' decision-making processes (Naroso et al., 2019), are selected, while decisions affecting productivity and sustainability (Cooper, 2011), such as the adoption of new management and pollution-preventing technologies, were also selected.

Table 1. DAHBSIM list of drivers of change

External drivers	Internal drivers
- Climate change - Policy and regulations - Market prices	- Crop rotation - Irrigation techniques - Knowledge about management - Tillage methods - Adoption of new management techniques - Adoption of pollution preventing technologies

4. FLOWS outputs and indicators

Table 2 shows the FLOWS model outputs and the AEI deduced from them. FLOWS outputs give daily values of water and solute transport and transformations, as well as, the optimal daily irrigation volumes. These outputs will be translated into quantities as shown in the second column in Table 2. Then, the AEI can be obtained as shown in the third column in Table 2.

Table 2. FLOWS outputs, quantities that can be deduced from it and the Agro-Environmental Indicators, AEI

FLOWS output	Quantities deduced from FLOWS outputs	Indicators under any specific scenario
Water fluxes	GW recharge (m^3/ha/y)	GW recharge / total water supply (rainfall & irrigation)
Water fluxes to runoff	Overland flow (m^3/ha/y)	Overland flow / total water supply (rainfall & irrigation)
NO_3 Concentrations Water Fluxes	NO_3 total mass percolation below root zone (kg/ha/y)	Percolated NO_3 / Total NO_3 supply
NO_3 fluxes to runoff Water fluxes to runoff	NO_3 total mass to surface water (kg/ha/y)	NO_3 mass to runoff / Total NO_3 supply
NH_4 Concentrations Water Fluxes	NH_4 total mass percolation below root zone (kg/ha/y)	Percolated NH_4 / Total NH_4 supply
NH_4 fluxes to runoff Water fluxes to runoff	NH_4 total mass to surface water (kg/ha/y)	NH4 mass to runoff / Total NH_4 supply
PO_4 Concentrations Water Fluxes	PO_4 total mass percolation below root zone (kg/ha/y)	Percolated PO_4 / Total PO_4 supply
PO_4 fluxes to runoff Water fluxes to runoff	PO_4 total mass to surface water (kg/ha/y)	PO_4 mass to runoff / Total PO_4 supply

Root water uptake distribution along soil profile	Actual transpiration, Ta (m^3/ha/y)	Overall water stress = 1 - Ta/Tp
Irrigation fluxes	Irrigation volumes (m^3/ha/y)	Application efficiency = 1 - (runoff + percolation)/irrigation
Organic carbon mass	Organic C residual mass in the root zone (kg/ha/y)	Total annual increase (+) or reduction (-) in organic C budget in the root zone (kg/ha/year)
CO_2 fluxes	CO2 emissions to the atmosphere (kg/ha/y)	CO_2 emission / Organic carbon from fertilizers and crop residuals in root zone

In general, the FLOWS outputs are 1-D quantities that are obtained by solving the Richards Equation for water flow and the Advection-Dispersion Equation for solute transport. Such outputs will be transformed into meaningful quantities, e.g., m^3/ha/y for water and kg/ha/y for solute transport. AEIs are generally dimensionless values that represent a system's efficiency in water consumption, nutrient consumption, etc.

5. DAHBSIM scenarios and indicators

The concept of scenarios is used in a wide variety of literature (Van Notten et al., 2003; Börjeson et al., 2006) including in the planning of farm systems under future conditions and their main drivers (Hossard et al., 2013). There are many definitions of scenarios made by different authors. According to Rotmans (1998) "scenarios are *hypothetical*, describing possible future pathways; describe *dynamic processes*, representing sequences of events over a period of time; consist of *states, driving forces, events, consequences and actions* which are causally related; start from an *initial* state (usually the present), depicting a *final state* at a fixed time horizon". According to Van Notten (2006) "scenarios are consistent and coherent descriptions of alternative hypothetical futures that reflect different perspectives on past, present and future developments, which can serve as a basis for action.".

The scenarios and hypotheses to be tested in DAHBSIM (Dynamic Agricultural Household Bio-Economic Simulator) are given in Table 3. The first scenario which is our base year scenario (Sc_Base) will serve the model calibration and validation. The reference scenario (Sc_Ref) will run the model without any changes. Best management practices scenario (Sc_Bmp) will run the model and simulate the impact of best management practices (changes in irrigation system, inter-cropping etc.) while maintain the current activities. Pollution preventing technology scenario (Sc_Ppt) will run the model and simulate the impact of pollution preventing technologies (bioreactors, constructed wetland etc.) while maintain the current activities. Combined scenario (Sc_Comb) will run the model and simulate the impact of simultaneous implementation of best management practices and pollution preventing technologies and the impact of incentives while maintain the current activities.

Table 3. Scenarios and hypotheses for DAHBSIM

Scenario Definition	**Details of the scenarios**	**Hypothesis to test**
Base year scenario – Sc_Base	Current activities for 2024	Calibrate and validate the model the year of the survey.
Reference scenario (2024-2040) – Sc_Ref	Current activities under climate, policy and market conditions	We take the assumption without any interventions the

		water, soil, pollution increase.
Best Management Practices Scenario–Sc_Bmp	Sc_Ref + implementation of best management practices	Improvement in terms of reduction of pollution, an increase of productivity, increase in labour use.
Pollution Preventing Technology Scenario–Sc_Ppt	Sc_Ref + implementing pollution preventing technologies (bioreactors, constructed wetland, etc.)	Reduction of pollution, Maintenance of the activity, increase in labor use
Combined Scenario – Sc_Comb	Sc_Ref + combination of scenario 1 and 2 + incentives	Important reduction of pollution, increase in productivity

Indicators are essential tools to assess the performance of a farm system. An indicator is a measure that describes, under certain criteria, a phenomenon and represents the state or trend of a specific situation (Gallopin, 1996; Neset et al., 2019; Papageorgiou et al., 2021). The list of selected indicators, their detailed definitions and their way of calculating in the NPP-SOL project is given in Table 4.

Annual farm income, total production, productivity (per hectare and labour), and economic resilience indicators were selected as socio-economic indicators, ecological resilience, nitrate, water consumption, animal welfare, GHG emissions as environmental indicators, the adoption rate of pollution prevention technologies as social indicators, crop diversity and irrigation as agronomic indicators and public and training costs were selected as policy indicators.

Table 4. Indicators organized according to the scenarios to be tested in DAHBSIM

Indicators	**Domain**	**Source**	**Definition of indicators**	**Way to calculate**
Annual farm income (euro/ha)	Socio-economics	Model	Net income from all farming activities (Sanginga et al., 2003; Twomlow et al., 2006)	(Revenue from crop activities – cost) + (Revenue from livestock activities – cost)
Total production (kg)	Socio-economics	Model	Total quantity of agricultural products (crops, trees, milk, meat)	Sum of production quantities of all activities
Productivity of land (euro/ha)	Socio-economics	Model	Output value per hectare (Ryan et al., 2016)	Output divided by total land area
Productivity of labour (euro/annual working units)	Socio-economics	Model	Efficiency of labour measured by output generated per labour (Dillon et al., 2016)	Output divided by number of labours or labour hours
Economic resilience	Socio-economics	Model	Farmer reported adaptation in responses to challenges (Owenya, 2012)	Number or percentage of farms that cover their variable costs
Ecological resilience	Environmental	Model	Farmer reported adaptation in responses to challenges (Owenya, 2012)	Assessments of soil quality above the initial state

Nitrate (kg/ha)	Environmental	Model	Amount of nitrate used or applied (Schröder et al., 2003)	Total mineral fertilization divided by total land area
Water consumption (m3 per kg per crop)	Environmental	Model	Total water used to produce a kg of a specific crop	Total water used divided by total crop production
Animal welfare (density)	Environmental	Model	Measurement of living conditions for animals, such as sufficient space for unimpaired health (Fraser, 2008)	Number of animals divided by the total barn area (m2)
GHG emissions (per kilogram of food product)	Environmental	Model	GHG emissions associated with producing one kg of food, including livestock-related emissions (Tarawali et al., 2011)	Emissions calculated as t CO2 equivalent per kg of milk, meat or feed produced
Adoption of pollution preventing technologies (%)	Social	Primary data from survey	Adopted on % of total land or % of households adopting (Degrande et al., 2013; Schmitt-Olabisi, 2012)	Percentage of households adopting pollution preventing technologies
Crop diversity (%)	Agronomic	Model	Genetic diversity as number of varieties planted (Zhu et al., 2000)	Average number of varieties per crop type
Irrigation (m3 per kg of food product)	Agronomic	Model	Amount of water applied to produce one kg of food products (Wani et al., 2003)	Total irrigation water volume divided by the total food production
Public costs (€/per household)	Policy	Model	Expenses by public institutions such as subsidies or regulations (Gameroff and Pommier, 2012)	Total cost of policies or subsidies divided by person
Training costs (€/ per household)	Policy	Model	Expenses by training programs provided (Gameroff and Pommier, 2012)	Total cost of training programs divided by person

6. Indicators for improvement with respect to the current scenario

ImI compare the AEI and BEI obtained from any alternative scenario with respect to the current scenario. Table 5 shows, as an example, the agro-environmental ImI based on the FLOWS model outputs. Generally, the ImI represent the change in AEI or BEI coming from adopting an improved management scenario.

Table 5. Agro-environmental ImI based on FLOWS model outputs and their corresponding thresholds

FLOWS output	Indicators for improvement (ImI)	Thresholds
Water fluxes	% change in GW recharge	To be set by each local SHR-HUB
Water fluxes to runoff	% change in overland flow	
NO_3 Concentrations	% change in NO_3 deep percolation	
Water Fluxes		
NO_3 fluxes to runoff	% change in NO_3 mass to runoff	
Water fluxes to runoff		
NH_4 Concentrations	% change in NH_4 deep percolation	
Water Fluxes		
NH_4 fluxes to runoff	% change in NH_4 mass to runoff	
Water fluxes to runoff		
PO_4 Concentrations	% change in PO_4 deep percolation	
Water Fluxes		
PO_4 fluxes to runoff	% change in PO_4 mass to runoff	
Water fluxes to runoff		
Root water uptake distribution along soil profile	% change in yield (based on total actual transpiration)	
Irrigation fluxes	Change in percentage of application efficiencies	
Organic carbon mass	% change in organic carbon in the root zone	
CO_2 fluxes	% change in CO_2 emissions	

The periodical local SHR-HUB meetings will aim at setting the thresholds for each ImI, which will then fill the third column in Table 5. As explained before, the thresholds will be used then to select the SSBMP among the proposed improved scenarios.

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Annexes

Annex I- DAHBSIM Outputs

This section gives information about inputs and outputs in different modules of DAHBSIM (Flichman et al., 2016).

Biophysical Module

Nitrate Module
Inputs: Nitrogen from livestock Nitrogen from fertilizer Mulch from residues
Outputs: N stress coefficient (used to calculate next year's yields)

Water Module
Inputs: Monthly rainfall
Outputs: Water stress coefficient (used to calculate next year's yields)

Crop Module

Inputs: Crop yields
Outputs: Crop production Crop labour Residues for livestock feed Residues sold Residues for mulch

Farm Module

Inputs: Market sales of crop and animal products Animal purchases Residues bought Meat produced Milk produced Seed quantity by cropping activity Animal purchases Animal sales
Outputs:

Seed purchases by cropping activity Farm labour Nitrogen fertilizer Nitrogen from livestock Residues from mulch Self-consumption Market purchases Farm income Animal activity income Crop activity income

Household Module

Inputs: Farm income Hired labour
Outputs: Household consumption

Livestock Module

Nutrient module
Outputs: Monthly livestock feed requirements

Livestock Module
Inputs: Crop residue availability for livestock feed
Outputs: Milk production Meat produced from slaughtered animals Purchased animals Sold animals Animals owned by the household Represents total nitrate excretion from livestock per household per year in kg Manure production Crop residues purchased

Risk Module

Inputs: Input use Seed purchases Buy prices

Market sales Animal purchases Sell prices
Outputs: Random net present value