LEarning and action alliances for NexuS EnvironmentS in an uncertain future

LENSES

Work Package 5

Deliverable 5.4: Guide for Ecosystem Services computational assessments

Nikolaos P. Nikolaidis, Maria A. Lilli, Antonia Maragkaki, Evangelia A. Koukianaki

Technical University of Crete (TUC)

February 2024

Project coordinator

Project partners

Project Website

This project is part of the PRIMA programme supported by the European Union.
GA n° [2041] [LENSES] [Call 2020 Section 1 Nexus IA]

Project no.	2041
Project acronym:	LENSES
Project title:	Learning and action alliances for NEXUS environments in an uncertain future
Call:	PRIMA call Section 1 – Nexus 2020, Topic 1.4.1-2020 (IA).
Start date of project:	01.05.2021
Duration:	36 months
Deliverable title:	D5.4– Guide for Ecosystem Services computational assessments
Due date of deliverable:	February 2024
Project Coordinator:	Stefano Fabiani, Council for Agricultural Research and Economics (CREA)

Organisation name of lead contractor for this deliverable: Technical University of Crete (TUC)

Lead authors	Nikolaos P. Nikolaidis, Maria A. Lilli (TUC)
Email	nikolaos.nikolaidis@enveng.tuc.gr
Contributions from	Mert Can Gunacti (EA-TEK), Cem Polat Cetinkaya (EA-TEK), Gulay Onusluel Gul (EA-TEK), Ali Gul (EA-TEK), Filiz Barbaros (EA-TEK), Sefa Nur Yesilyurt (EA-TEK), Silvia Vanino (CREA), Vassilios Pisinaras (SWRI), Andreas Panagopoulos (SWRI), Nabeel Bani Hani (NARC), Zübeyde Albayram Doğan (UTAEM)
Internal Reviewer 1	Alessandro Pagano
Internal Reviewer 2	Silvia Vanino (CREA)

Dissemination level

PU	**Public**	**PU**

History

Version	Date	Reason	Revised by
01	1 /	First Draft	Nikolaidis N., Maragkaki A.., Koukianaki E., Lilli M. (TUC)
02	15/2/2024	Contributions	Mert Can Gunacti (EA-TEK), Cem Polat Cetinkaya (EA-TEK), Gulay Onusluel Gul (EA-TEK), Ali Gul (EA-TEK), Filiz Barbaros (EA-TEK), Sefa Nur Yesilyurt (EA-TEK), Silvia Vanino (CREA), Vassilios Pisinaras (SWRI), Andreas Panagopoulos (SWRI), Nabeel Bani Hani (NARC), Zübeyde Albayram Doğan (UTAEM)
03	20/2/2024	Second draft	Nikolaidis N., Lilli M. (TUC)

04	2 /2/2024	Review	Alessandro Pagano, Silvia Vanino
05		Final	Nikolaidis N., Lilli M. (TUC)

Executive Summary

WP 5 aims to provide the methodological and practical foundations for the selection of a suite of solutions that use Nature-based Solutions (NBS) as an underlying principle for a Nexus approach. More specifically, the objective of Tasks 5.1 and 5.2 was the development of a framework (WEF Nexus Evaluation Framework) to assess ecosystem services provided by NBS while optimizing the Water-Ecosystem-Food (WEF) nexus of a basin. This framework was modified into a user-friendly module (website: nbscatalogue.lenses-prima.eu) (Deliverable 5.3), to allow the selection of NBS and was built on available methodologies and information for selecting NBS (Deliverable 5.1). Within Task 5.4 and the respective Deliverable (5.4), different modelling tools (SWAT, ICZ, HEC-HMS, WEAP) were used for the assessment of WEF Nexus, and different NBS scenarios (terraces, riparian forest, livestock management and agro ecological practices etc.) were used for its optimization. This Deliverable (D5.4) can be used as a guide report to transfer the knowledge for application to other countries.

The Karst-SWAT and the one-dimensional Integrated Critical Zone (1D-ICZ) models were used to simulate the impact of NBS on water quantity and quality as well as on soil ecosystem services of Koiliaris River Basin, which serves as an illustrative example of a basin that has experienced severe soil and biodiversity degradation. The Karst-SWAT model showed that a combination of NBS of terraces and riparian forest can reduce soil erosion and the sediment load by 97%. The 1D-ICZ model successfully simulated the soil-plant-water system and showed that agro ecological practices affect biomass production, carbon and nutrient sequestration, soil structure and geochemistry.

The HEC-HMS and WEAP models were used to simulate the impact of NBS on irrigation water efficiency and crop production, after applying NBS in the different LENSES pilots. Specifically, deep tillage, crop rotation, and organic manure practices increased the irrigation water efficiency up to a total of 70% and crop production up to a total of 95%. A reduction of irrigation based on the needs of the plants increased the irrigation water efficiency by a total of %60. Soil water management through irrigation scheduling and increased soil organic matter through mulching and mowing increased the irrigation water efficiency up to 23.5%. Intercropping and microbial fertilizer applications were shown to have no significant impact on irrigation water efficiency or crop production.

All NBS can directly or indirectly improve soil ecosystem functions and reduce soil threats. Hence, this report can be used as a guide to assess the application of NBS and their impact on ecosystem services.

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1. Introduction

1.1. Guide for ecosystem services assessment

WP 5 aims to provide the methodological and practical foundations for the selection of a suite of solutions that use Nature-based Solutions (NBS) as an underlying principle for a Nexus approach. More specifically, the objective of Tasks 5.1 and 5.2 was the development of a framework (WEF Nexus Evaluation Framework) to assess ecosystem services provided by NBS while optimizing the Water-Ecosystem-Food (WEF) nexus of a basin. This framework was modified into a user-friendly module (website: nbscatalogue.lenses-prima.eu) (Deliverable 5.3), to allow the selection of NBS and was built on available methodologies and information for selecting NBS (Deliverable 5.1) (Somarakis et al., 2019, Dimitru and Wendling, 2021). Within Task 5.4, different modelling tools (SWAT, ICZ, HEC-HMS, WEAP) were used for the assessment of WEF Nexus and different NBS scenarios were used for its optimization. This Deliverable (D5.4) can be used as a guide report to transfer the knowledge for application to other countries.

To help the practitioners navigate the landscape of NBS selection and assessment, a roadmap/guide was created (Deliverable 5.2) in which the NBS practitioner has to follow a stepwise approach, which phases are described below and represented in Figure 1.

1. **Develop a vision for the landscape in consultation with the local stakeholders.** This vision drives the project and the potential local stakeholders to achieve consensus and overcome the many barriers that will rise from its implementation. To develop such a vision, it is important to identify the environmental and ecological problems of the area in order to define a holistic approach to solving them that would give added value to the region and enhance its resilience. This vision brings local stakeholders and decision-makers on board to materialize the project (Lilli et al., 2020b).
2. **Identify the challenges the area/basin under consideration is facing regarding the WEF Nexus.** These challenges can be viewed at this stage separately for each component of the Nexus.
3. **Select the appropriate NBS bundles, applying the WEF Nexus Evaluation Framework**. Use the module (nbscatalogue.lenses-prima.eu) to select a primary list of appropriate NBS that address the vision for the landscape and the challenges. Through the module, the desired ecosystem services to obtain from the landscape as well as the approaches needed to improve ecosystem services are identified (Deliverable 5.3). Through the module, Key Performance indicators (KPIs) are provided in order to assess their technical effectiveness; effectiveness in improving service

under specific conditions, climate resilience of the solution and contribution to adaptation. The selections made should be consistent with the vision identified in step 1.

4. **Evaluate the list of potentially applicable NBS** that contribute to more than one component of the WEF Nexus.
5. **Model simulations (SWAT, ID-ICZ, HEC-HMS, WEAP).** Once the list of potential NBS has been selected the framework was augmented by assessing their ecosystem services provided using different models. These simulations will provide more specific KPIs for the alternatives which can then be used by the stakeholders to accept or revise the list of NBS until the WEF Nexus of the area is optimized.
6. **Revise the list** until the NBS list that optimizes the WEF Nexus is finalized.

1.2. Overview of the approach

Sustainable land management requires the maximization of the efficacy of soil ecosystem functions (and the related services) as well as the minimization of soil threats. In addition, sustainable land management has to be considered in terms of optimizing the WEF Nexus necessitating the use of hydrologic, water allocation, geochemical models that assess not only the WEF Nexus, but also soil ecosystem functions and threats.

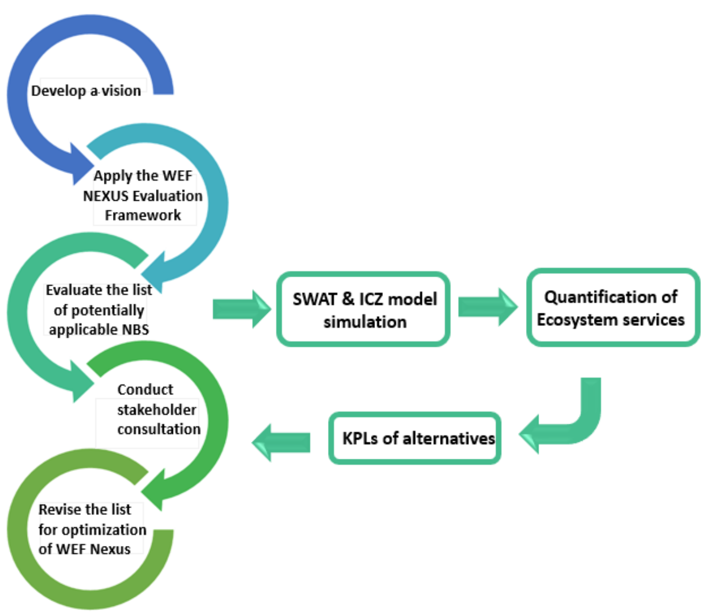


Figure 1: Guide to help the pilots to navigate the landscape of NBS selection and assessment.

Implementation of the NBS in the different pilots has the individual or combined benefits of improving soil and water health, irrigation water efficiency, crop production, etc. Simulating these local effects on a larger scale (river basin) and considering their impact on water resources has value on several levels as simulating their impact on water accounting provides tools for the decision-makers, and motivation to local stakeholders to increase their NBS uptake.

The objective of this report is to illustrate how hydrologic, water allocation and ecosystem-based mathematical models can be used to simulate the impact of NBS on ecosystem functions and their related services as well as minimize soil threats. Ecosystem functions include biomass production, carbon and nutrient sequestration, water filtration and transformation and biodiversity. Whereas soil threats include loss of soil carbon and nutrients, loss of biodiversity, erosion and soil compaction. Different NBS (terraces, riparian forest, livestock management and agro ecological practices etc) were assessed in terms of their impact to WEF Nexus. All NBS can directly or indirectly improve soil ecosystem functions and reduce soil threats. Hence, this report can be used as a guide to assess the application of NBS and their impact on ecosystem services.

2. Methodology

In this report we will assess NBS that deal with soil erosion control, livestock management and agroecological practices. The methodology is described on the model that has been used. In this particular case we use the karst –SWAT model in the Koiliaris River Basin to assess erosion control and livestock management, the ID-ICZ model to assess agroecological practices and the WEAP model was used to assess impact of NBS on water allocation to all LENSES pilots.

2.1. Control of soil erosion with NBS

2.1.1. Site description and WEF challenges

The Koiliaris River Basin is situated 15 km east of the city of Chania in Crete. The total watershed area covers 130 km^2 with the primary water source originating from the White Mountains. Over the past two decades, the Koiliaris River watershed has undergone a comprehensive investigation (Lilli et al., 2020a; Lilli et al., 2020b; Giannakis et al., 2014; Vozinaki et al., 2015; Moraetis et al., 2015; Kourgialas et al., 2011; Nerantzaki et al., 2015; Nerantzaki and Nikolaidis, 2020; Morianou et al., 2017; Vozinaki et al., 2011; Sibetheros et al., 2013; Yu et al., 2019). The geological composition of the region, coupled with a significant fault running in a northeast–southwest direction, directs water movement toward the springs within the Koiliaris River Basin (Steiakakis et al., 2023; Steiakakis et al., 2018). The study area encompasses karst systems with a distinctive characteristic possessing unique hydraulic properties and transmissivities (Kourgialas et al., 2010). The karst area outside the river basin but feeding into it covers 80 km^2 (Nerantzaki et al., 2015; Lilli et al., 2020a), while the total length of the river is 36 km.

The main WEF related challenges that need to be addressed focus on three geographic areas within the basin of Koiliaris (Area 1: the western part of the basin, Area 2: the southern part of the basin and Area 3: the northeastern part of the basin) (Figure 1). Area 1 presents intense soil degradation, particularly erosion due to cultivation of olive groves in steep slopes without the development of any terraces. Area 2 biodiversity degradation resulting from free-grazing livestock at the higher elevations of the basin and Area 3 presents land degradation due to unsustainable agricultural practices (soil tillage, no organic matter addition to soil, high pesticide and herbicide use). The challenges were extensively presented in Lilli et al. (2024). The Koiliaris River watershed serves as an illustrative example of a basin that has experienced severe soil and biodiversity degradation (Nerantzaki et al., 2015; Moraetis et al., 2015; Sibetheros et al., 2013).

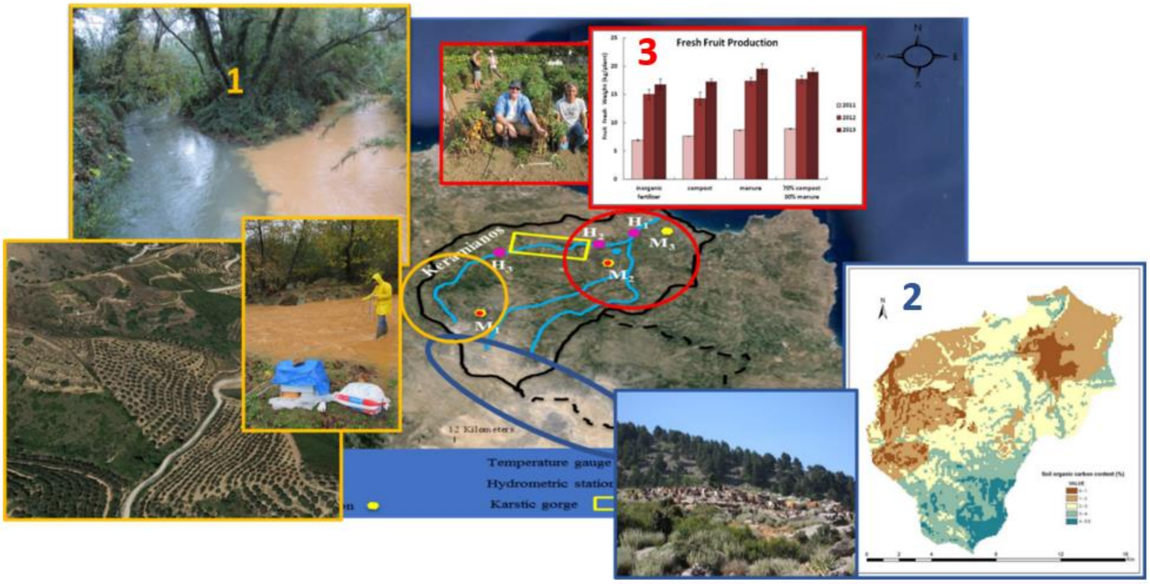


Figure 2: Approximate extent of the areas of the watershed related to the main challenges to be addressed at the Koiliaris CZO.

2.1.2. Model description

The SWAT (Soil and Water Assessment Tool) model (Neitsch et al., 2011) is a widely utilized hydrological model designed to simulate and predict the impact of land management practices on water resources at the watershed scale. Developed by the United States Department of Agriculture (USDA), SWAT integrates various components, including hydrology, weather, soil, vegetation, and land use to simulate the complex interactions within a watershed. The model utilizes spatially distributed data on topography, soil properties, weather conditions, and land use to simulate processes such as water flow, sediment transport, nutrient cycling, etc. It's important to note that the SWAT model cannot simulate karst formation (Nikolaidis et al., 2013). This limitation arises from the assumption that water surpassing the deep aquifer is lost from the system. In karstic formations, water from the deep aquifer contributes to the main river flow through a pothole. To address this, the karstic model was introduced (Nikolaidis et al., 2013), retrieving water from the deep aquifer and directing it into two reservoirs, subsequently feeding the surface flow again. In the aforementioned case study, specifically in the gorge of the watershed where karstic formations exist, the majority of the surface flow passes through a pothole and discharges downstream.

2.1.3. Modeling NBS in Area 1 and 2

In order to mitigate soil erosion and enhance water quality in Area 1, two different NBS, enclosed the establishment of terracing and riparian forest were implemented and assessed through modeling. The

SWAT model has been already implemented for the Koiliaris River Basin regarding the hydrology, sediment transport, and nutrient concentrations(Nerantzaki et al., 2015, Sibetheros et al., 2013, Nerantzaki & Nikolaidis, 2020). In the context of this study, the simulation was extended until 2020 and the results are presented in Figures 3 and 4. Table 2 presents the maximum, mean and minimum flow for the years 2010-2020 at the two stations.

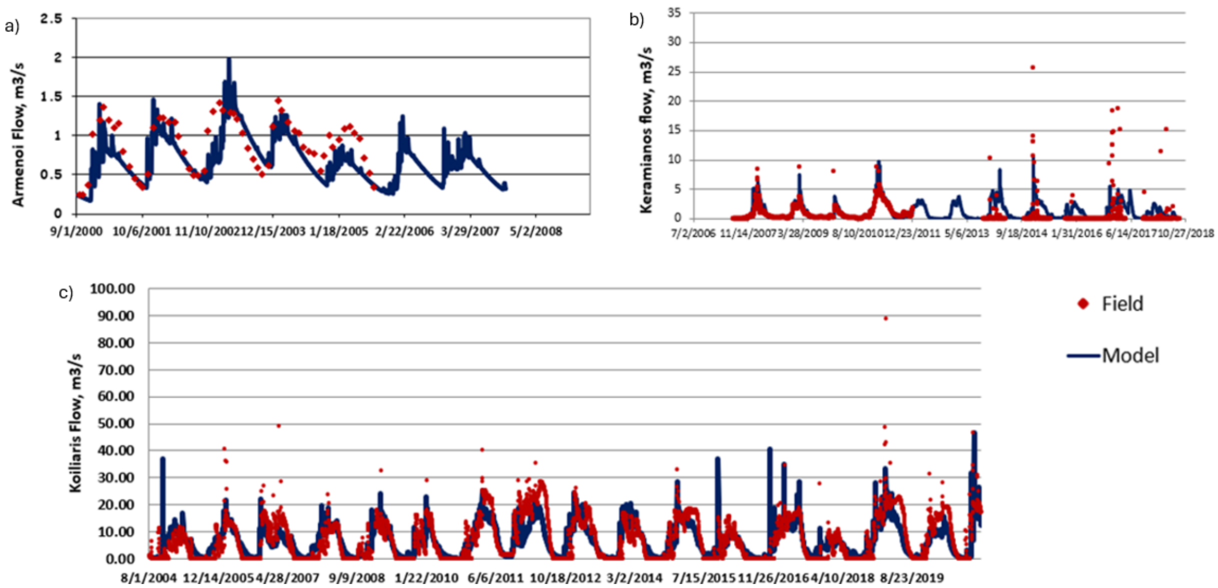


Figure 3: Simulation of hydrology of : a) Armenoi spring b) Keramianos tributary c) Koiliaris River .

Terraces were introduced into the model by defining the USLE practice factor, which depends on the slope of the selected terrace, the average slope length (TERR_SL), which relates to soil morphology, and the curve number (TERR_CN), which depends on the slope range (Neitsch et al., 2011). These modifications were applied for each Hydrologic Response Unit (HRU) contained in subbasins of the model that comprise Area 1 (9 and 15), corresponding to the Keramianos tributary. The riparian forest was emulated in the SWAT model as filter strips at the HRU level on both sides of the river. The filter strip module was applied to subbasins 9 and 15 which are comprised of agricultural land (AGRL), pasture (PAST) and olive groves (OLIV) land uses (Figure 5). The filter strip related model parameters included the ratio of field area to filter strip area (VFSRATIO), the fraction of the HRU that drains to the most concentrated ten percent of the filter strip area (VFSCON), and the fraction of flow within the most concentrated ten percent of the filter strip that is fully channelized (VFSCH). In subbasin 9, for the AGRL land use, the average ratio of field area to filter strip area was 2% and for the PAST land use, it was 1%. In subbasin 15, for the OLIV land use and for the PAST land use, the ratio of field area to filter strip area was 2.5 and 0.5 respectively.

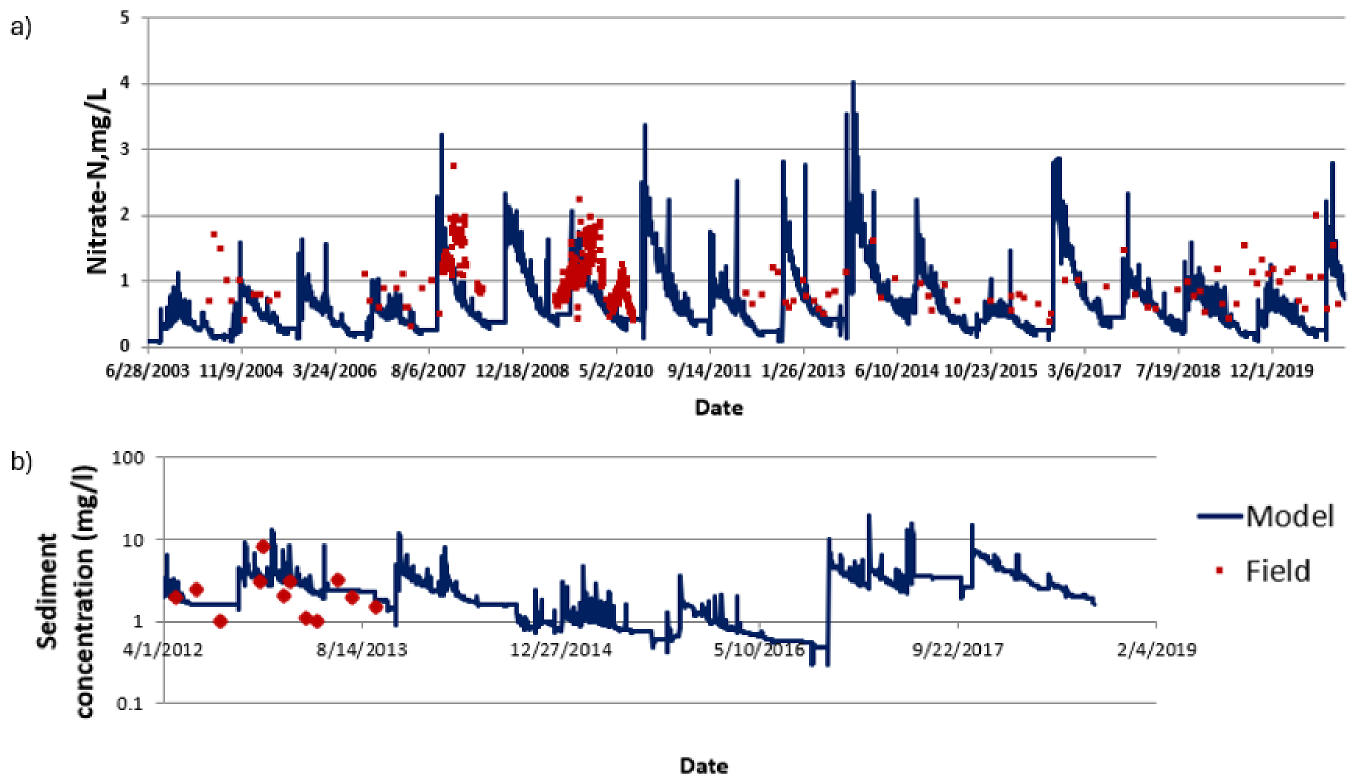


Figure 4: Simulation of the chemistry of the Koiliaris River Basin: a) Nitrate-N simulation b) Sediment simulation.

Table 1: Minimum, mean and maximum flow at the two stations.

Hydrometrics Stations	Max Simul. Discharge m^3/s	Mean Simul. Discharge m^3/s	Min Simul. Discharge m^3/s
Ag.Georgios	36.04	2.65	0.12
Keramianos Tributary @ gorge entrance	10.66	1.33	0.01

In Area 2, the strategy involved discontinuing the free grazing of livestock at high elevations and transitioning to organized caged livestock systems in lower elevations (Figure 6). This strategic shift aimed to alleviate the environmental pressures from livestock grazing in the highlands, allowing in this way the gradual restoration of biodiversity and facilitating the recycling of manure and reuse for agriculture. To model this NBS within the calibrated SWAT, all model operations associated with manure fertilization from sheep and goats in designated areas were eliminated.

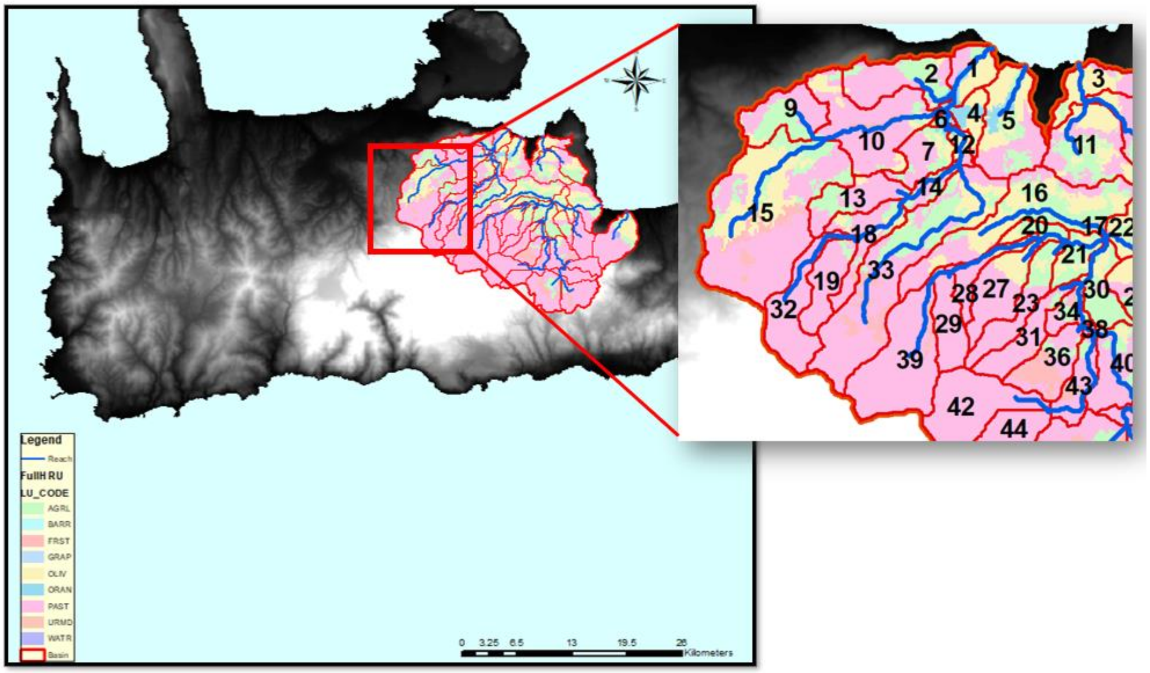


Figure 5: Land uses in subbasins 9 and 15.

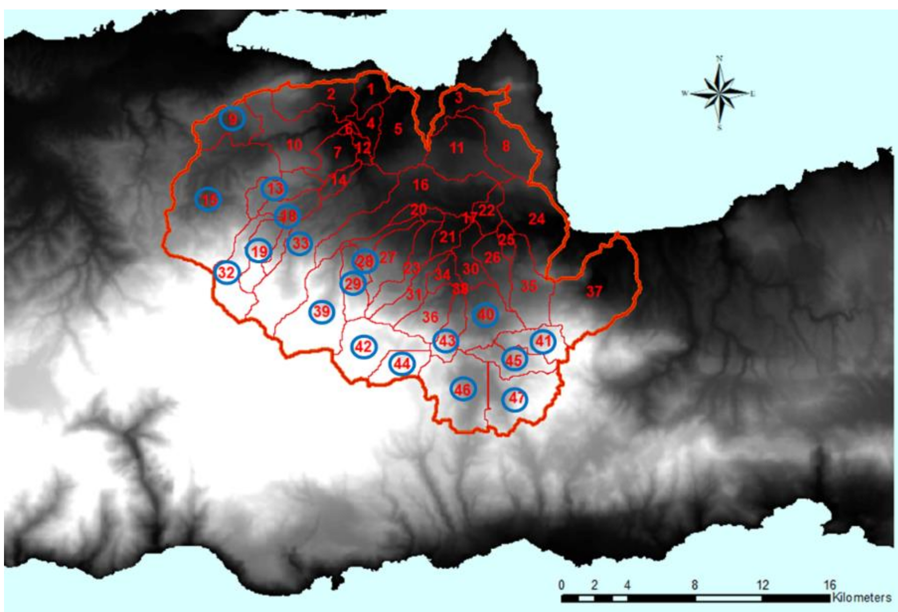


Figure 6: The subassins from which the manure was removed

2.2. Using agro ecological practices for soil restoration

2.2.1. Model description

The one-dimensional Integrated Critical Zone (1D-ICZ) model is a mechanistic mathematical model capable of simulating and quantifying key soil functions including food and biomass production, water flow and storage, carbon/nutrient sequestration and biodiversity (Kotronakis et al., 2017; Giannakis et al., 2017). The model couples soil formation (aggregation and disaggregation) and structure with soil hydrology, cycling of nutrients, plant productivity and weathering (Kotronakis et al., 2017; Nikolaidis et al., 2014). The 1D-ICZ model consists of four sub-modules: HYDRUS-1D, CAST, PROSUM and SAFE Weathering. HYDRUS-1D sub-module simulates water flow, heat and solute transport and the chemical weathering sub-module simulates the dissolution kinetics of minerals. PROSUM sub-module simulates the plant dynamics i.e. biomass production, water and nutrient uptake and litter production of C and N (Kotronakis et al., 2017; Giannakis et al., 2017; Nikolaidis et al., 2014). The Carbon, Aggregation and Structure Turnover (CAST) sub-module is the core model that uses the RothC carbon pools and thus simulates the macro-aggregate formation (around POM) and disruption to form micro-aggregates and silt-clay sized micro-aggregates (Giannakis et al., 2017; Stamati et al., 2013). The CAST model has been used globally (Damma Glacier in Switzerland, Heilongjiang Mollisols in China, Koiliaris and Milia in Greece, Clear Creek in USA, Slavkov Forest in Czech Republic and Marchfeld in Austria) in order to simulate the soil structure, C/N/P dynamics and especially C sequestration (Panakoulia et al., 2017).

2.2.2. Modeling NBS in Area 3

The assessment of agroecological practices and the resulting impact on soil ecosystem functions and services was conducted using the 1D-ICZ model for an avocado plantation located (Latitude: 35.43717, Longitude: 24.1427, Elevation: 15 m) in the Koiliaris river basin. Agroecological practices used in the plantation included manure addition, mulching and grass incorporation in the soil, sustainable irrigation practices etc. and they have been applied to the field since 2010. The avocado plantation consists of 25 large trees (6-year-olds) and 40 smaller ones (4-year-olds) irrigated through drip irrigation with a piping system of 25 and 15 drips respectively. Moreover, the avocado trees were fertilized and each December 10 kg/tree of manure was added to the soil. The model was calibrated to simulate the plant biomass production, carbon/nutrient sequestration, soil formation (aggregation and disaggregation) and soil nutrient concentrations for the period 2016−2023. As boundary conditions, monthly time series of air temperature (T, °C), evapotranspiration (ET), precipitation (PCP), irrigation (in m) (Figure 7), photosynthetic active radiation (PAR, μmol/m^2/s), fertilization (NO_3, NH_4, PO_4, K in t/ha), manure and organic matter addition (tC/ha) were used. More specifically, the available daily data (T, PCP, PAR) were gap-filled and then converted into monthly time series. The input time series of ET were calculated using the Penman-Monteith equation for the period of available data (2019−2022) and then gap filled to complete the 2016−2023 time series. To simulate soil structure dynamics, Water Stable Aggregate (WSA) Fractionation data for the years 2016, 2019 and 2023 were used. For the years 2016 and 2019, two soil samples (0-5 and 15-20 cm) were collected and analyzed in duplicates and aggregated to determine the WSA Fractionation for these years. For the year 2023, triplicate soil samples (0-20 cm) were collected from the avocado plantation and analyzed. The method used to separate the soil is analytically described by Elliott (1986) and Lichter et al. (2008). The available nutrient concentrations measured at the well located within the field were compared to the simulated nutrient concentrations of the fourth soil layer (30-40 cm) as the soil profile was defined to be at 40 cm, discretized in five nodes and four layers. The groundwater in the area is shallow and the water depth varies between 1-2 m below ground. Once the model is calibrated, then the impact of agro ecological practices on soil functions and nutrient emissions can be assessed.

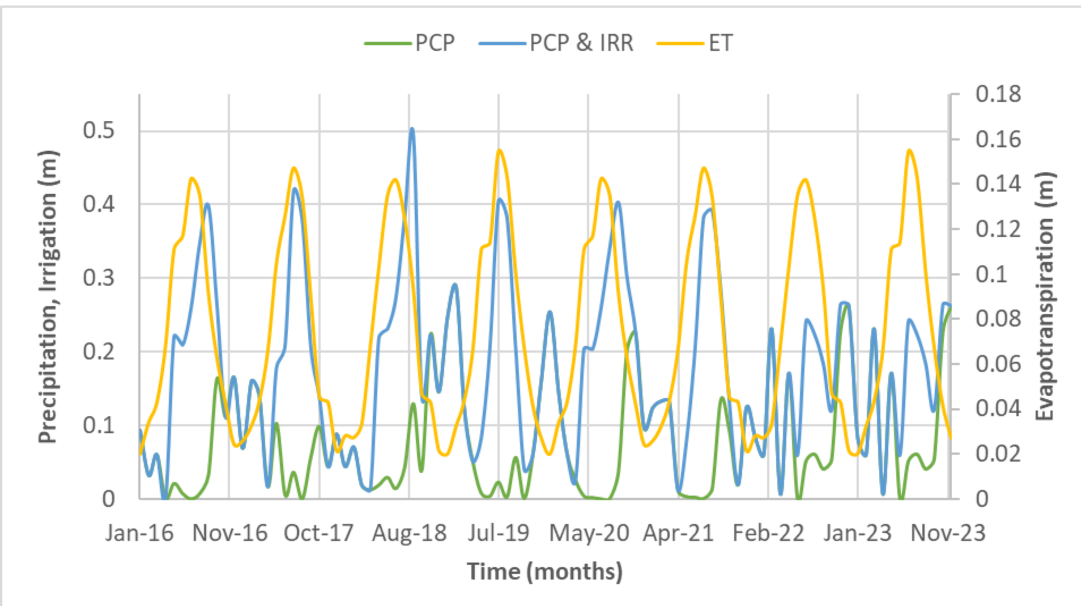


Figure 7: Precipitation, precipitation & irrigation and evapotranspiration input data.

2.3. Impact of NBS on Water allocation

2.3.1. Development of the Water Accounting Models

One of the main tasks of the LENSES project is the simulation of the various implementations (such as effects of climate change, demand management, applications of NBS, etc.), where these applications have been realized within a limited boundary such as a plot or a portion of the area in a river basin. Through these simulations, we can estimate the results of these applications/conditions and give feedback to relevant actors/decision-makers to help them optimize, prioritize, and make decisions for the economic, social, and environmental benefits of the communities living in the area.

Development of the water accounting models requires two main sub-tasks such as; the development of the hydrological model, and the topological network of the related river basin. A topological network is a sketch of a system to visualize the elements interacting with each other. In particular, the water resources systems usually consist of; water supply nodes such as rivers, and reservoirs, demand nodes such as agricultural plots, industry sites, urban areas demanding water for domestic use, environmental nodes such as wetlands, etc., and the links between these nodes connecting them such as the conveyance systems (pipelines, open channels, etc.). On the other hand, through the development of the hydrological models, the hydrological cycle in the pilot area is understood. Using the observed meteorological data such as precipitation, temperature, relative humidity, wind speed, etc. a simple or complex model can be built. Hydrologic Engineering Center- Hydrologic Modeling System (HEC-HMS) and Soil and Water Assessment Tool (SWAT) software have been employed for this task. Water Evaluation and Planning System (WEAP) software has been utilized to combine the hydrological models with the topological network described by the pilots for the water accounting task. Development of the baseline and other simulated scenarios have been conducted using the WEAP software.

2.3.2. Models description

The **Hydrologic Engineering Center- Hydrologic Modeling System (HEC-HMS)** is a software developed by the US Army Corps of Engineers. The model is capable of simulating rainfall-runoff events and directing hydrological processes. Integrated with HEC-Geo-HMS, it can seamlessly import spatial data for the study area, allowing the representation of key parameters such as infiltration, evaporation, and the overall hydrological dynamics of the river basin. HEC-HMS has a generalized modeling system that can represent a large number of different basins. The model comprises key components, including a catchment model, a meteorological model, control features, time series data, and grid data. It incorporates components for precipitation, potential evaporation, snowmelt, canopy, surface storage, infiltration, surface runoff, baseflow, channel routing, and channel losses. These components collectively enable the simulation of land surface processes of the hydrological cycle. Users can tailor the model by selecting the most appropriate representation of catchment characteristics. Within the model, "Subbasin" is used to represent the physical basin, "Reach" to convey the flow, "Junction" to combine the flow from different upstream sources, "Source" to represent the water sources, "Diversion" to model the flow leaving the main channel and reservoir elements (HEC-USACE, 2008).

The Soil & Water Assessment Tool (SWAT) is another influential modelling tool in the field of hydrology developed by the United States Department of Agriculture (USDA) (Arnold et al., 1998; Neitsch et al., 2011). It is specifically designed for simulating hydrological processes at the watershed scale and has been widely used for assessing the impacts of climate variability, land use changes, and management practices on streamflow and water quality. SWAT's capabilities and flexibility make it well-suited for addressing the complex challenges posed by climate change. Successful applications of the SWAT model have been demonstrated across various disciplines in regions with diverse geographical conditions and different climate zones worldwide (Gassman et al., 2007; Onusluel Gül and Rosbjerg, 2010; Onusluel Gül et al., 2010). SWAT is particularly effective in capturing the interactions between land use, soil, and climate in a watershed. It integrates data on topography, land use, soil properties, weather, and management practices to simulate various hydrological processes, including evapotranspiration, runoff, infiltration, and groundwater flow. The model divides the watershed into sub-basins and uses a variety of algorithms to simulate the movement of water and sediments within the watershed.

Water allocation modeling component of the project is carried out by the **Water Evaluation and Planning System (WEAP)** software developed by the Stockholm Environment Institute (SEI). WEAP is a software tool that is commonly used in studies that are focused on integrated approaches to water resources planning problems (Lévite et al., 2003; Cetinkaya and Gunacti, 2018). WEAP provides several built-in models for rainfall runoff and infiltration, evapotranspiration, crop requirements and yields, surface water/groundwater interaction, and instream water quality on a monthly time scale. It also serves to identify the variables and equations on relations between the elements of the basin or the processes involved. WEAP is linked to a GIS interface to build up the topology of the entire basin and the links between demand and supply nodes (Mounir et al., 2011; Nivesh et al., 2023). The basin system is defined in terms of its supply sources (e.g., rivers, creeks, groundwater, reservoirs, and desalination plants);

withdrawal, transmission, and wastewater treatment facilities; water demands; pollution generation; and ecosystem requirements. The modelling flowchart of a common WEAP Model is given in Figure 8.

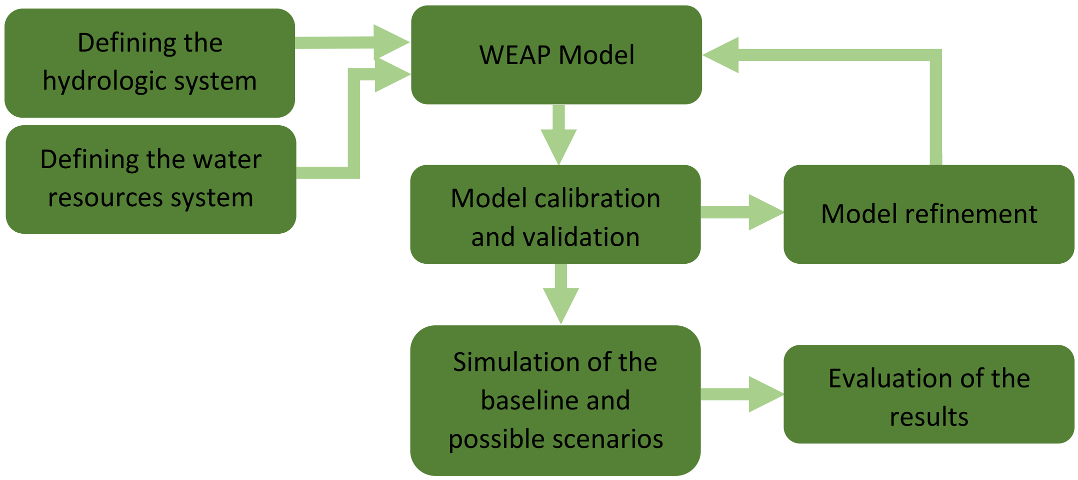


Figure 8: Modeling process of a common WEAP model

2.3.3. Defining the baseline and NBS scenarios

The baseline scenarios for each pilot have been developed with the observed data provided by the pilots. They represent the current conditions of the pilots. To simulate the baseline conditions of the pilots, several 1 on 1 teleconferences with local experts, local data, and feedback from the stakeholders have been considered to finalize the calibration and validation processes of the models. Results of the baseline (and other scenarios as well) have been evaluated with the water accounting indicators, which represent the different domains of the WEF Nexus. The baseline results of the water accounting indicators define a basis for the comparison of the NBS scenario results.

On the other hand, NBS scenarios represent each pilot's effort on NBS implementations in their respective pilot areas. While pilots have implemented several different NBS solutions to improve their soil and water conditions, irrigation water efficiency, and crop production, the effects of these applications vary (Table 1). Although there are a lot of other NBS applications available in the literature and practice, only the applications realized by the pilots have been simulated to estimate their impact on the pilot's water accounting. According to the pilots' testimonial answers, the application rate and observed impacts of the chosen NBSs have been considered in the water accounting models (Table 2).

Table 2: NBS scenarios by the pilots and their impacts

Pilot Area	Selected NBSs	Implementation percentage (% of pilot area)	Impacts	
			Irrigation Water Efficiency Increase Rate (%)	Crop production Increase Rate (%)
Deir Alla	Increase soil water holding capacity and infiltration rates by deep tillage for soil	70	15	25
	Soil improvement Fertility due to N-Fixation by using legume plant in crop rotation	50	10	20
	Incorporating organic manure	100	25	30
	Crop Rotation	50	20	20
Koiliaris	Reduction of irrigation based on the needs of the plants	100	60	-
Pinios-Agia	Effective soil water management through irrigation scheduling	12,23	23,49	-
	Increasing soil organic matter through mulching and mowing practices			
Pinios-Delta	Effective soil water management through irrigation scheduling	8,04	22,37	-
	Increasing soil organic matter through mulching and mowing practices			
Tarquinia	Change crop rotation	100	40	40
	Incorporating manure, compost, biosolids, or crop residues to enhance carbon storage	100	25	30

3. Results and discussion

3.1. NBS Simulation for mitigating soil erosion

3.1.1. Terrace and Riparian Forest Simulation

To mitigate soil erosion in Area 1 of the Koiliaris watershed, three distinct scenarios were examined. The first scenario entailed the implementation of terraces in the Keramianos tributary, identified through sampling surveys as the source of erosion. The second scenario involves the establishment of riparian forests in these subbasins, and the third scenario combines the two approaches. To fully understand how the SWAT model simulates terraces, a sensitivity analysis was conducted on key model parameters (TERR_CN, TERR_SL, USLE practice factor). The tested range for the TERR_CN was between 40 and 45. The upper value of 45 was obtained from the hydrologic calibration which depicts the current unprotected slope conditions and the lower value from the scientific literature. The values of average slope length (TERR_SL) chosen to simulate were 3, 4, 5, 6, 10, and 15 meters while five categories of slopes were chosen: 0-2%, 2-8%, 12-16%, 16-20%, and 20-25%. Figure 9 presents the results of the calculated SYLD from the model, varying the slope length and USLE practice factor in subbasins 9 and 15 where terracing was applied. The values defined for the implementation of the filter strip in specific HRUs were calculated under the assumption that the width of the riparian forest on both sides of the channel is 40 m. Table 3 shows the values of selected parameters used for the simulation of the terraces and the filter strip.

Table 3: Values of selected parameters for the implementation of terraces and filter strip.

	terraces			filter strip			
Name of parameter	TERR_P	TERR_CN	TERR_SL	VFSI	VFSRATIO	VFSCOIN	VFSCH
Value of parameter	0.10	45	4	1	0.6 - 6	0.5	0

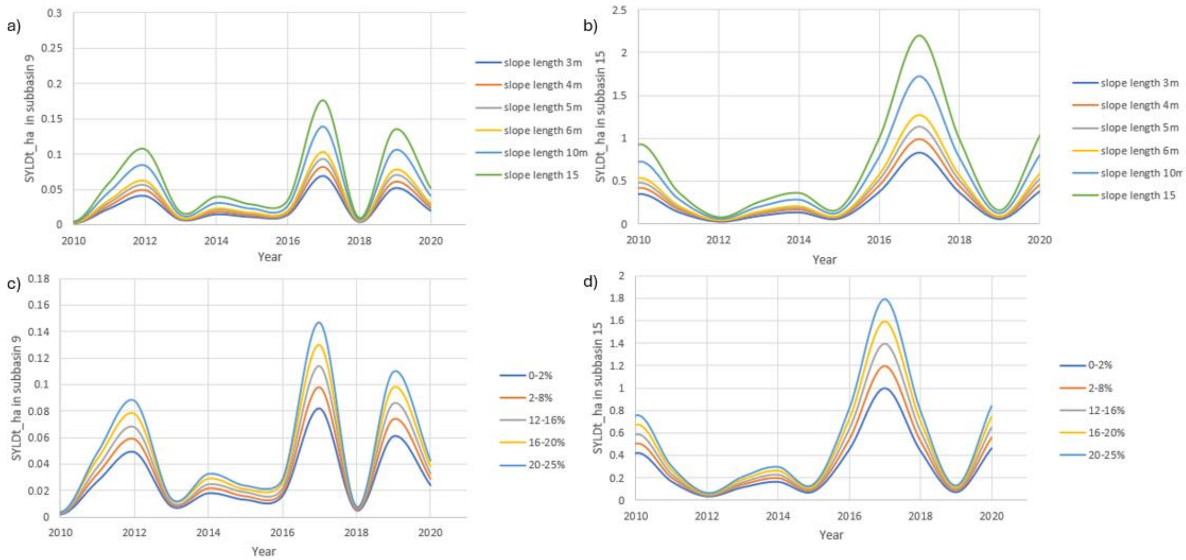


Figure 9: SYLD from the model, varying the : a) slope length in subbasin 9 b) slope length in subbasin 15 c) USLE practice factor in subbasins 9 d) USLE practice factor in subbasins 15

Table 4 presents the average sediment load, the range of sediment load and the percentage reduction for each scenario. In subbasin 9, the average sediment load was 0.175, 0.012 and 0.011 t/ha for the first, second and third scenarios respectively, while the average sediment load was 0.176 t/ha for the case of non-implementing NBS. The percentage sediment reduction was calculated to be 1%, 93% and 94% for the first, second and third scenario respectively (Table 4). The results suggest that the most efficient individual NBS in subbasin 9 is the implementation of riparian forest. In subbasin 15, the average sediment load was 0.270, 3.147 and 0.168 t/ha for the first, second and third scenario respectively, while the average sediment load was 5.337 t/ha for the case of non-implementing NBS. The percentage sediment reduction was calculated to be 95%, 41% and 97% for the first, second and third scenario respectively (Table 4). The results suggest that the most efficient individual NBS in subbasin 15 is the implementation of terraces. The third scenario, combining the individual NBS, demonstrates the highest percentage of sediment reduction in both subbasins (Table 4). The results suggest that a combination of terraces and the creation of a riparian forest can reduce significantly (up to 97% reduction) the sediment loads exported from the basin.

Table 4: Impact of the different scenarios in sediment load values for subbasin 9 and 15.

	Subbasin 9		
Scenarios	Average Sediment load (t/ha)	Range of sediment load (t/ha)	Percentage reduction (%)
wo NBS	0.176	0.022-0.806	-
Terraces	0.175	0.021-0.810	1
Riparian Forest	0.012	0-0.058	93
Combination of NBS	0.011	0-0.057	94
	Subbasin 15		
Scenarios	Average Sediment load (t/ha)	Range of sediment load (t/ha)	Percentage reduction (%)
wo NBS	5.337	0.446-24.250	-
Terraces	0.270	0.024-1.258	95
Riparian Forest	3.147	0.081-16.102	41
Combination of NBS	0.168	0.005-0.868	97

In addition to the quantitative results that were obtained through modelling for the impact of NBS on ecosystem services, Table 5 presents a list of benefits and co-benefits that are derived from these actions on the WEF Nexus. A series of benefits and co-benefits related to water, ecosystem and food include erosion control, flood mitigation, climate resilience and regulation, carbon sequestration and nutrient cycling, increase in quantity and quality of food production etc.

Table 5: Qualitative summary on terraces and riparian forest impact soil services and threats

Water	Ecosystem	Food
NBS - Terraces		
○ **Water Conservation:** Terraces help in retaining water on sloped or hilly terrains. This contributes to better groundwater recharge. ○ **Erosion Control:** One of the main purposes of terracing is	○ **Soil Erosion:** Terracing helps reduce soil erosion by slowing down the flow of water on sloping terrain, sustaining valuable topsoil and maintaining soil fertility.	○ **Increased Arable Land:** Terracing creates level and flat platforms on slopes, effectively increasing the amount of arable land available for cultivation and thus food production.

<table>
<tr>
<td>to reduce soil erosion. By breaking the slope into smaller steps, the speed and force of water runoff are decreased.
○ Flood Mitigation: Terraces slow down the flow of water and reduce its overall volume during heavy rainfall events, which can help prevent flash floods downstream.
○ Irrigation: Terraced fields are better suited for irrigation purposes.
○ Water Quality Improvement: Terraces act as natural filters, trapping sediments and pollutants carried by runoff water.
○ Groundwater Recharge: Terracing can help replenish groundwater reserves by allowing rainwater to percolate into the soil rather than quickly running off the surface.</td>
<td>○ Agricultural Productivity: By creating more flat and stable areas for cultivation, terracing can expand the available agricultural land, increasing food production.
○ Biodiversity Conservation: In some cases, terracing can create diverse microhabitats with varying moisture levels and sunlight exposure. These different ecological niches may support a variety of plant and animal species, contributing to biodiversity conservation.</td>
<td>○ Diversification of Crops:The creation of terraces enables farmers to grow a wider variety of crops due to better water distribution and reduced soil erosion risks. Diversification can enhance food diversity and resilience to external shocks.
○ Climate Resilience: Terraced landscapes can enhance resilience to climate change impacts, such as extreme weather events and water scarcity..
○ Farming Practices: Terracing encourages sustainable farming practices, such as crop rotation, integrated pest management, and reduced chemical usage. These practices contribute to sustainable food production and the long-term health of agricultural ecosystems.</td>
</tr>
<tr>
<td colspan="3">○ Sustainable Water Management: By promoting soil health and reducing erosion, terracing helps maintain a healthy ecosystem that supports water retention and water quality over the long term. Terraces act as water-retaining structures, allowing water to be stored in the terraced fields. This can help regulate water flow, prevent flooding, and ensure a steady water supply for crops and downstream users.This contributes to more sustainable water management practices.</td>
</tr>
<tr>
<td colspan="3">NBS - Riparian Forest</td>
</tr>
<tr>
<td>○ Water Quality Improvement: Riparian forests act as natural buffers, filtering and purifying water that flows through them. They trap sediment, nutrients, and pollutants, improving water quality downstream.
○ Flood Mitigation: Riparian forests act as natural flood barriers. During heavy rainfall or high-water events, the</td>
<td>○ Erosion Control: The roots of riparian forest vegetation help stabilize the soil along riverbanks, reducing erosion and preventing the loss of valuable topsoil. This helps protect agricultural land and maintain soil fertility.
○ Habitat for Biodiversity: Riparian forests create diverse habitats for a wide range of plant and animal</td>
<td>○ Nutrient Cycling: Riparian forests act as buffers, filtering water that flows through them and trapping sediments and nutrients. As a result, they play a role in nutrient cycling, providing essential nutrients to adjacent agricultural lands. These nutrients support crop growth and enhance agricultural productivity,</td>
</tr>
</table>

dense vegetation slows down the water flow and absorbs excess water, reducing the risk of flooding in downstream areas. o **Regulation of Water Temperature:** Riparian vegetation provides shade to the water, regulating water temperature. Cooler water temperatures are beneficial for various aquatic species, particularly in hot climates, as they support biodiversity and aquatic ecosystems. o **Groundwater Recharge:** The presence of riparian forests can facilitate groundwater recharge. As water infiltrates through the forest floor, it recharges underground aquifers, maintaining groundwater levels and supporting base flow in rivers during dry periods. o **Climate Resilience:** Riparian forests play a role in climate change adaptation. Their preservation and restoration can increase the resilience of ecosystems to extreme weather events, such as droughts and floods, thus maintaining water availability for various needs. o **Carbon Sequestration:** Riparian forests are significant carbon sinks, absorbing and storing carbon dioxide from the atmosphere. Protecting these forests helps mitigate climate change and reduce greenhouse gas emissions.	species. These habitats serve as breeding grounds and shelters for wildlife, contributing to biodiversity conservation and supporting fisheries. o **Biodiversity Support:** Riparian forests provide valuable habitats for a wide variety of plant and animal species. These habitats serve as important corridors for wildlife movement and promoting biodiversity conservation. o **Habitat Connectivity:** Riparian forests can connect different ecosystems, such as upland forests and wetlands, allowing for the movement and migration of species. This connectivity enhances ecological resilience and helps maintain ecosystem balance. o **Climate Regulation:** Trees in riparian forests sequester carbon dioxide, playing a role in climate regulation and helping to mitigate the impacts of climate change. o **Recreation and Tourism:** Riparian forests offer opportunities for activities such as hiking, birdwatching, and fishing. o **Biodiversity Conservation**: Riparian forests support a diverse range of plant and animal species. Preserving these ecosystems contributes to biodiversity conservation and maintains ecological balance.	contributing to food production. o **Pollination Support:** Riparian forests provide habitat for pollinators, such as bees and butterflies. These pollinators play a crucial role in pollinating crops, leading to increased crop yields and improved food production. o **Sustainable Agriculture Practices:** By protecting riparian forests, farmers can adopt sustainable agriculture practices that benefit food production.

○ **Sustainable Water Management:** By preserving riparian forests, water managers can ensure sustainable water management. These forests contribute to the regulation and maintenance of water flow, helping meet the demands for water resources in a balanced manner.

3.1.2. Discontinuation of livestock free grazing impact

The exclusion of livestock from the upland pasture areas was simulated by discontinuing the input of manure in these HRUs. Table 6 presents the annual average nitrate export from the Koiliaris River Basin, comparing scenarios with and without livestock activity. According to the calculations performed, the mean annual nitrate export per hectare associated with livestock activity, amounted to 9.8 kg/ha/yr, whereas in the absence of livestock activity, the corresponding figure was 7.9 kg/ha/yr. The observed reduction in nitrate levels, as depicted in Table 6, is approximately 19%. The results illustrate the impact of livestock activities on water quality.

Table 6: Annual average nitrate export for each scenario.

Scenarios	Average NO_3-N (mg/L)	Range of NO_3-N (mg/L)	Percentage Removal (%)
Livestock activity	0.79	0.20-4.36	-
wo Livestock activity	0.64	0.18-3.35	19

In addition to the quantitative results that were obtained through modelling for the impact of NBS on ecosystem services, Table 7 presents a list of benefits and co-benefits that are derived from this action on the WEF Nexus. A series of benefits and co-benefits related to water, ecosystem and food include erosion control, flood mitigation, climate resilience and regulation, carbon sequestration and nutrient cycling, increase in quantity and quality of food production etc.

Table 7: Qualitative summary on how livestock management impact soil services and threats

Water	Ecosystem	Food
○ **Water Quality Improvement:** Livestock farming can lead to water pollution through the discharge of manure and other agricultural runoff. By	○ **Nutrient Cycling:** Livestock manure can serve as a valuable source of nutrients for soil and plants. When managed properly, the recycling of nutrients	○ **Increase in food production:** recycling of manure and its use as a fertilizer can increase food production and be beneficial to soil health.

reducing the concentration of livestock in certain areas, the potential for water contamination decreases, leading to improved water quality. ○ **Reduced Erosion and Sedimentation:** Intensive livestock farming can contribute to soil erosion and sedimentation of water bodies.	through manure can enhance soil fertility and support agricultural productivity. ○ **Restoration of upland biodiversity:** Removal of free grazing livestock removes the pressure from the ecosystem and the upland area will recover their biodiversity. ○	○ **Improvement in production quality:** With established livestock farming, the manure of sheep/goats can be utilized as a product for organic fertilization. This will reduce the production and use of chemical fertilizers.

3.2. Agro ecological practices simulation and assessment

Figures 10-13 present the results of the simulation of the 1D-ICZ regarding biomass production, carbon/nutrient sequestration, soil structure and geochemistry. Figure 10 shows the evolution of the limiting factors of Avocado growth. It is evident that temperature affects plant growth the most. This is consistent with other studies which suggest that temperature affects growth and concentration of dry matter in avocados (Lahav, Trochoulias, 1982). Avocados' optimal temperature for growth is between 20-25°C. More specifically, the optimal air temperature during nighttime is greater than 10°C and the optimal range during daytime fluctuates from 20 to 30°C (Bhore et al., 2021). At high temperatures (above 30°C) root growth and dry matter production decreases and at low temperatures enzymatic activity and metabolic processes decline (Lahav, Trochoulias, 1982; Tzatzani et al., 2023). The reduction of dry matter results in low nutrition worthy avocados and the deceleration of enzymatic activity slows down maturation (Tzatzani et al., 2023).

Figure 11 illustrates the simulated Annual Gross Primary Production (GPP) compared to the field measurement (x spot) of the year 2023. To simulate GPP, the Avocado tree is considered to be at steady state regarding its biomass production. The GPP remains stable over the years with the average annual GPP to be 1474.6 gC/m^2 (Figure 11). Figure 12a presents the comparison of the simulated and measured WSA mass contained in silt-clay sized micro-aggregates (AC1), micro-aggregates (AC2) and macro-aggregates (AC3). One can observe that the majority of WSA mass (71.9%) is contained in the macro-aggregates (>250μm). The WSA mass contained in the micro-aggregates (53-250 μm) is 24.7% and the WSA mass contained in the silt-clay sized micro-aggregates (<53 μm) is 3.4%. Figure 12b shows the comparison of SOC and the organic carbon (OC) contained in AC1, AC2, cPOM (coarse particulate organic matter) and AC3 between the model and the field (set aside). SOC increases from 70.1 to 88.6 tC/ha/month during the period 2016−2023. Most of the OC is contained in cPOM and AC3 and the least amount of OC is contained in AC1. The OC contained in AC1 increases from 4.0 to 9.0 tC/ha, in AC2 decreases from 11.6 to 6.7 tC/ha and in cPOM and AC3 increases from 54.5 to 72.9 tC/ha. Figure 13 shows the comparison of TOC (Total OC), IC (Inorganic carbon), TN (Total N), DIN (Dissolved Inorganic N), NH_4−N, PO_4−P, F^-, SO_4^{2-}, H^+, K^+, Mg^{2+}, Ca^{2+} and Na^+ well measurements with the daily simulated nutrients concentrations for the fourth soil layer (30-40cm) in mol/L. The results suggest that the 1D-ICZ model is capable in simulating the soil geochemical conditions as well as the whole soil-plant-water system.

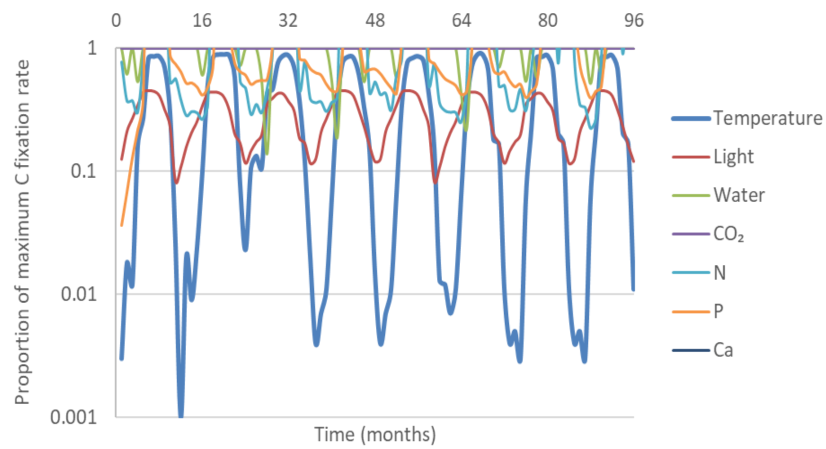


Figure 10: Limiting factors of growth over time (2016-2023).

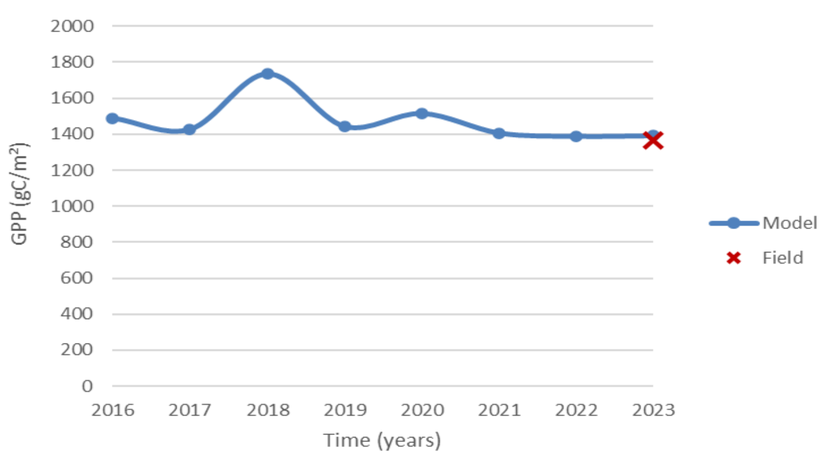


Figure 11: Comparison of simulated annual GPP with field measurement.

The impact of agroecological practices on the plant-water-soil ecosystem is presented in Table 8 which is a summary of the ecosystem services derived from such management practices. The majority of WSA were found in macro-aggregates (71.9%) while the WSA in micro-aggregates (AC2) and silt-clay sized micro-aggregates (AC1) account for 24.7 and 3.4% respectively. The soil is sandy (75.9% sand) and the C to N ratio is 13. The biomass production is 14.7 tC/ha/yr and the C sequestration is 80.7 tC/ha/yr (with the cPOM accounting for the 80.5% of the below-ground C content). The N sequestration estimated at 6.2 tN/ha/yr and the CO_2 emissions at 8.3 tC/ha/yr. The leaching of the chemicals TOC, TN, PO_4-P and K to groundwater was calculated to be 1.3, 14.6, 2.2, and 7.1 g/m^2 respectively.

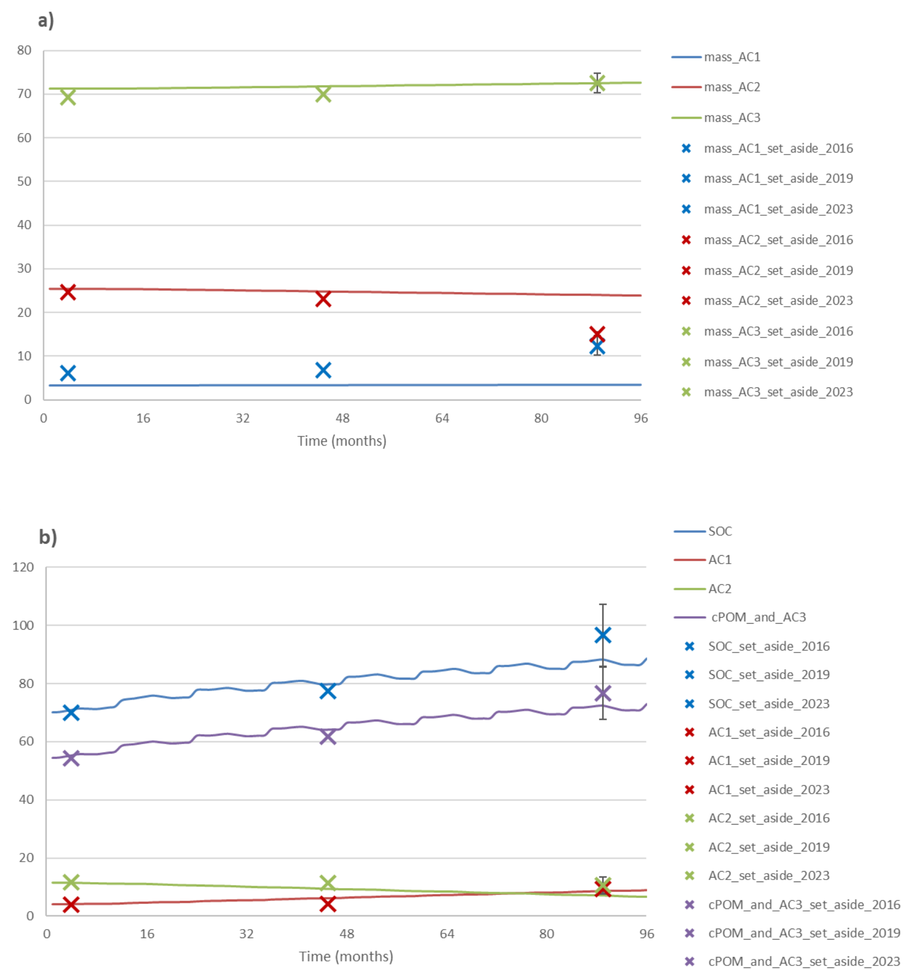
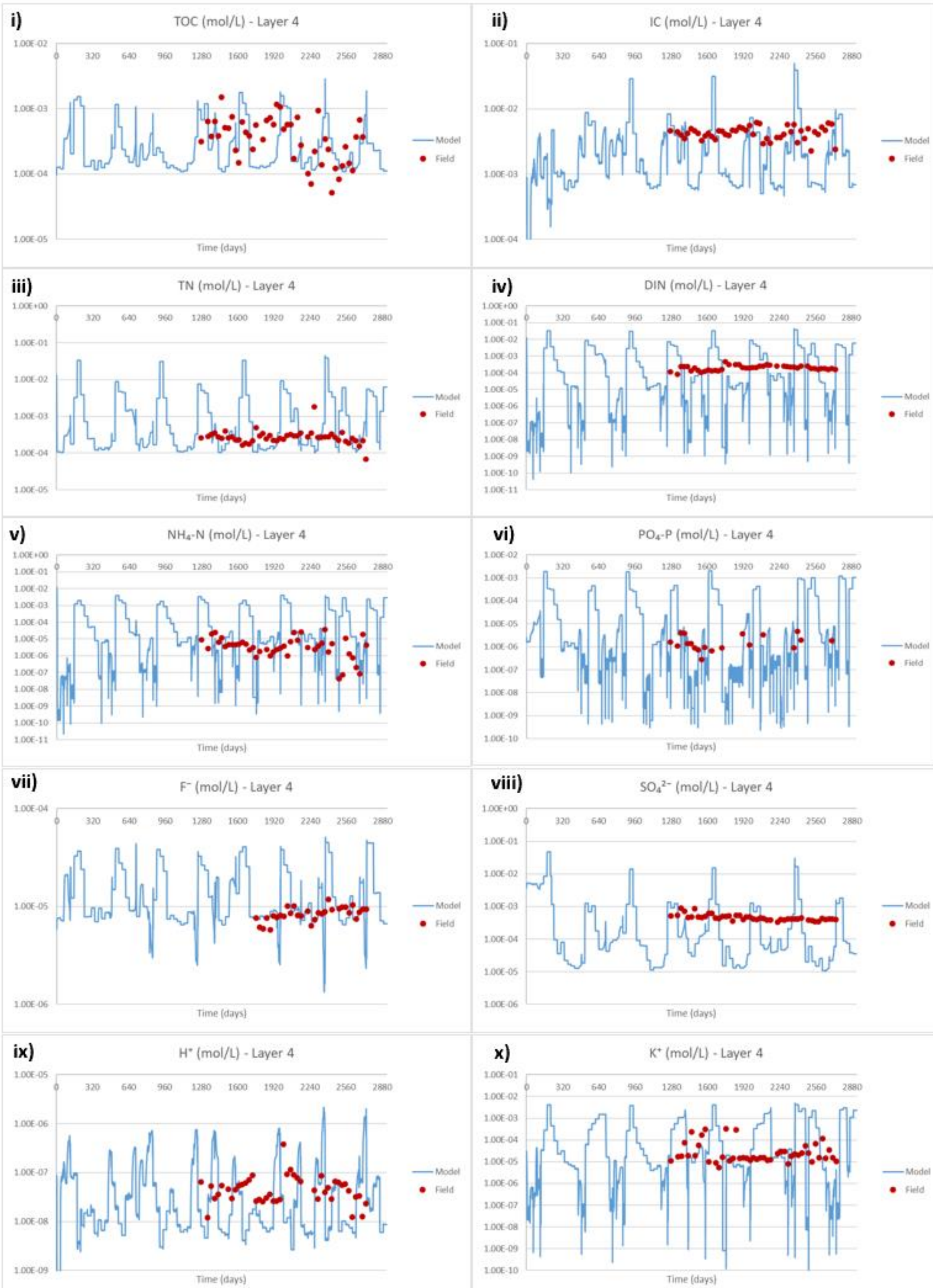


Figure 12: Comparison of simulated and measured a) WSA (%) and b) SOC and OC in AC1, AC2, cPOM and AC3 (tC/ha).


i) TOC (mol/L) - Layer 4
ii) IC (mol/L) - Layer 4
iii) TN (mol/L) - Layer 4
iv) DIN (mol/L) - Layer 4
v) NH4-N (mol/L) - Layer 4
vi) PO4-P (mol/L) - Layer 4
vii) F⁻ (mol/L) - Layer 4
viii) SO4²⁻ (mol/L) - Layer 4
ix) H⁺ (mol/L) - Layer 4
x) K⁺ (mol/L) - Layer 4
Time (days)
Model
Field

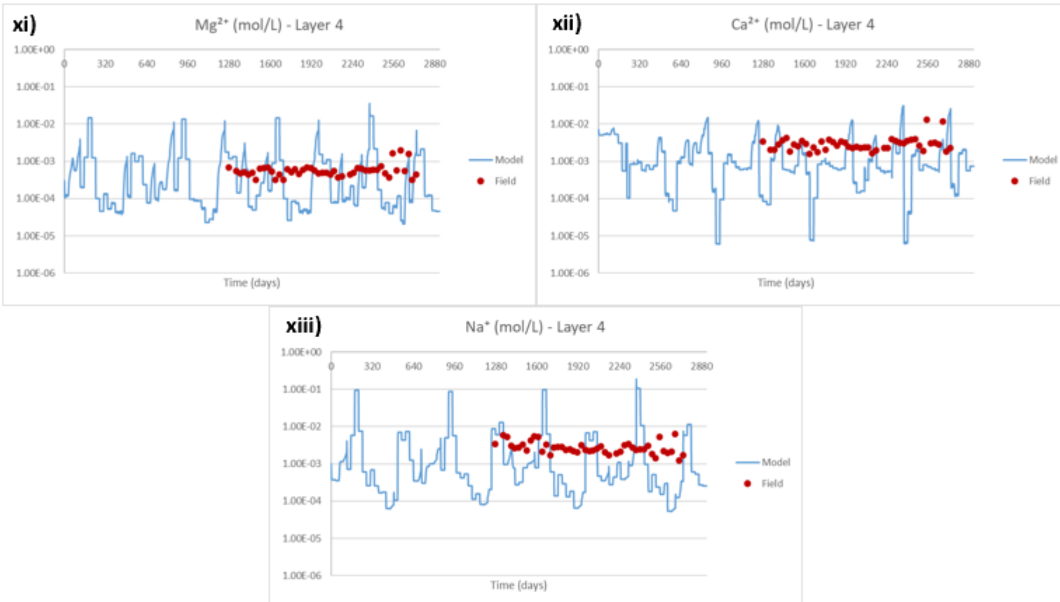


Figure 13: Comparison of daily measured geochemistry concentrations (from well) with simulated for the fourth soil layer over time in mol/L: i) TOC, ii) IC, iii) TN, iv) DIN, v) NH4-N, vi) PO4-P, vii) F^-, viii) $SO42^-$, ix) H^+, x) K^+, xi) $Mg2^+$, xii) $Ca2^+$ and xiii) Na^+. For the TOC, we compared the simulated concentration of BIO with the TOC measurements from the well. For the Inorganic Carbon, we compared the simulated concentration of HCO_3^- with the IC well measurements. For the Total Nitrogen, we compared the sum of the simulated concentrations of NH_4^+, NH_3, NO_3^- and LMWN (Low Molecular Weight N) with the TN measurements from the well. For the DIN, we compared the sum of the simulated concentrations NH_4^+ and NO_3^- with the sum of the well measurements of NH_4^+ and NO_3^-.

Table 8: Ecosystem services derived from agroecological practices at an avocado plantation.

Soil dynamics and structure parameters (related to soil fertility and soil health)	
WSA_AC3 (%)	71.9
WSA_AC2 (%)	24.7
WSA_AC1 (%)	3.4
Sand (%)	75.9
Silt-clay (%)	24.1
Biomass production	
Above ground C (tC/ha)	14.7
Below ground C (tC/ha)	80.7
Nutrient sequestration	
cPOM (tC/ha)	65.0

Below ground N (tN/ha)	6.2
cPOM (tN/ha)	2.1
C/N (below ground)	13.0
CO_2 emissions (tC/ha)	8.3
Leaching of chemicals to groundwater	
TOC, (g/m^2)	1.3
TN, (g/m^2)	14.6
PO_4–P, (g/m^2)	2.2
K, (g/m^2)	

3.3. NBS simulation for water allocation and assessment

In Deir Alla (Jordan), the pilot has implemented deep tillage, crop rotation, and organic manure practices which increased the irrigation water efficiency by a total of %70 and crop production by a total of %95. In Figure 14, the supply for agriculture decreases due to the NBS implementations yet overall, its effect remains minor. That is because all the sectors receive lower amounts of water than what they demand. In Figure 15 due to the effect of NBSs, agricultural and overall demand decreases. As the agricultural demands decrease, the pressure on the water resources also decreases; causing supply-demand ratios (Figure 16), reliability of the source (Figure 18), and coverage of the demand (Figure 19) to rise and unmet demands to go down (Figure 17). On the other hand, unmet instream flow demand (Figure 20), Water Exploitation Index (WEI) (Figure 21), and Groundwater Exploitation Index (GEI) (Figure 22) had minor fluctuations. Conversely, average irrigation productivity (Figure 23) and unit gross revenue (Figure 24) have increased significantly due to reduced water demand and increased crop productivity.

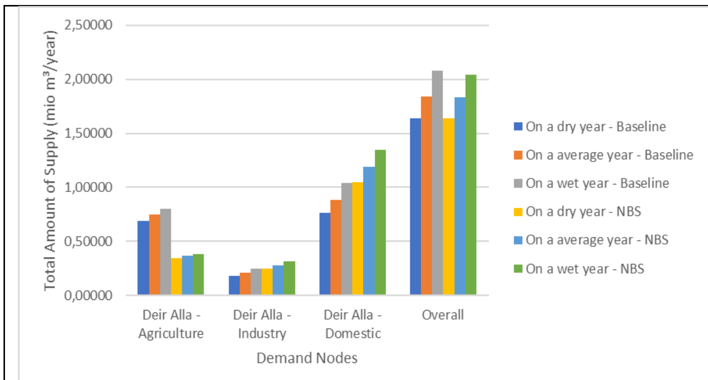


Figure 14: Total amount of supply according to Baseline and NBS scenarios in Deir Alla

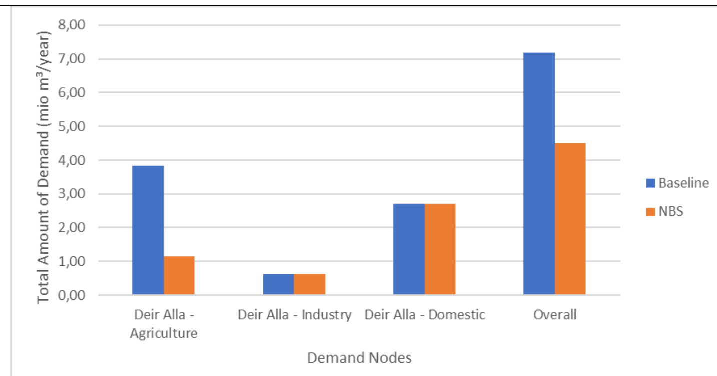


Figure 15: Total amount of demand according to Baseline and NBS scenarios in Deir Alla

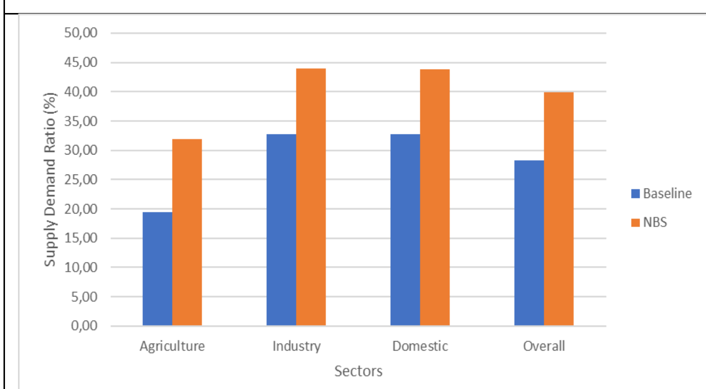


Figure 16: Supply demand ratio according to Baseline and NBS scenarios in Deir Alla

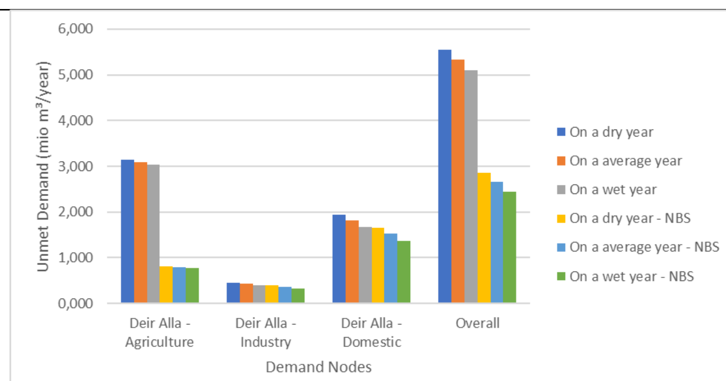


Figure 17: Total unmet demand according to Baseline and NBS scenarios in Deir Alla

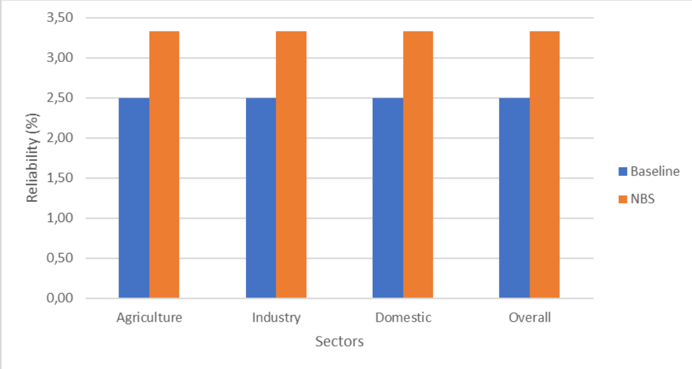


Figure 18: Reliability of source according to Baseline and NBS scenarios in Deir Alla

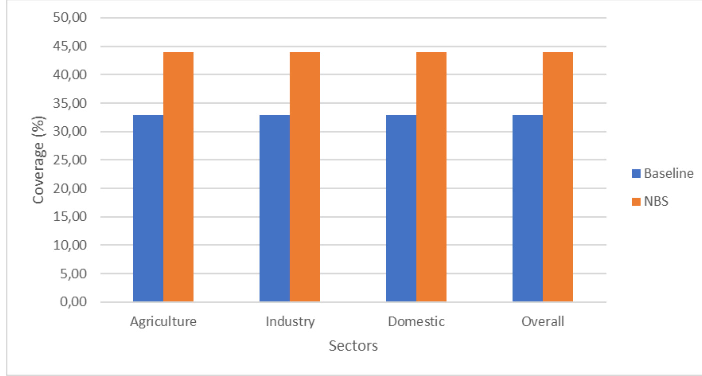


Figure 19: Coverage of demand according to Baseline and NBS scenarios in Deir Alla

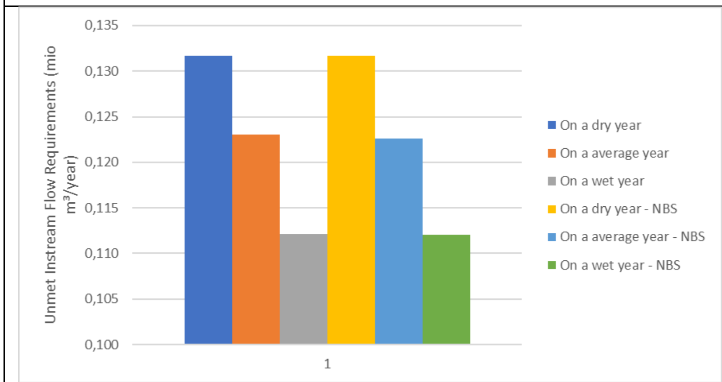


Figure 20: Unmet Instream flow demand according to Baseline and NBS scenarios in Deir Alla

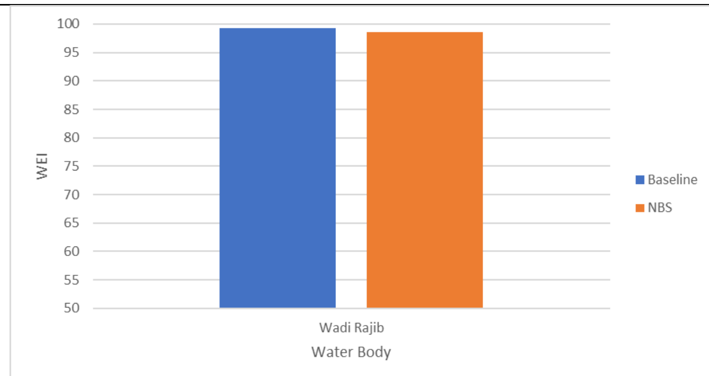


Figure 21: Water Exploitation Index according to Baseline and NBS scenarios in Deir Alla

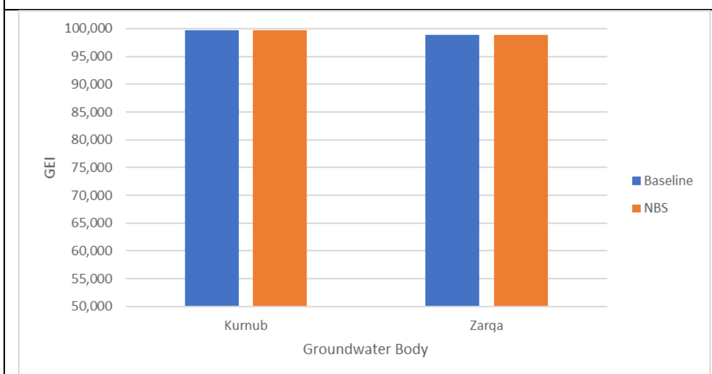


Figure 22: Groundwater Exploitation Index according to Baseline and NBS scenarios in Deir Alla

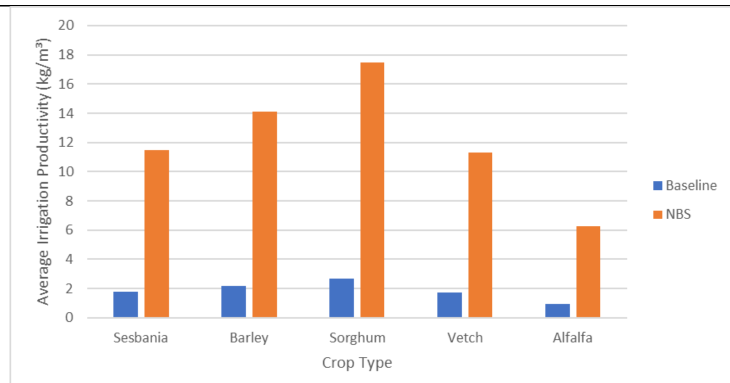


Figure 23: Average irrigation productivity according to Baseline and NBS scenarios in Deir Alla

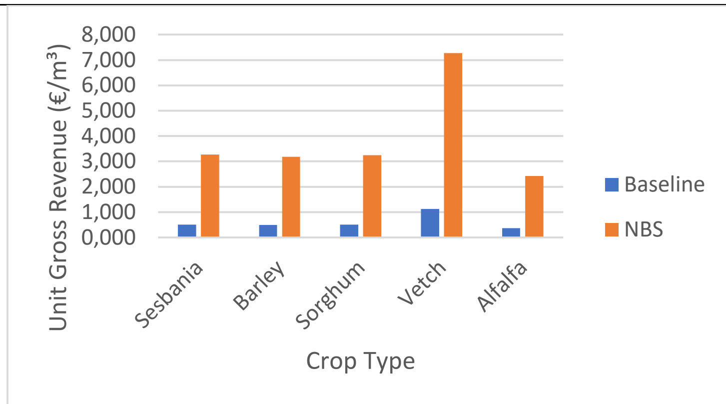


Figure 24: Unit gross revenue according to Baseline and NBS scenarios in Deir Alla

In Koiliaris (Greece), the pilot has implemented a reduction of irrigation based on the needs of the plants which increased the irrigation water efficiency by a total of %60. The pilot has also implemented terraces in the areas with high erodibility, applications of riparian forests, their combinations, and reduction of livestock activity in the mountainous area which was reported to have no significant impact on water accounting.

The results suggest positive outcomes as the supply for agriculture and hence the overall supply decreases (Figure 25), because the demand for agricultural water decreases (Figure 26). Decreased pressure on water resources sectors boosts the supply-demand ratio (Figure 27), and lowers the unmet demand so that its even nullified in some sectors for a wet year example (Figure 28). Reliability of source and coverage of demand have minor changes since pilot already had high values for these indicators (Figure 29, 30). GEI has decreased more significantly relatively in the regions where the agriculture was more dominant (Figure 31). Lastly, average irrigation productivity (Figure 32) and unit gross revenue (Figure 33) have increased significantly due to reduced water demand and increased crop productivity.

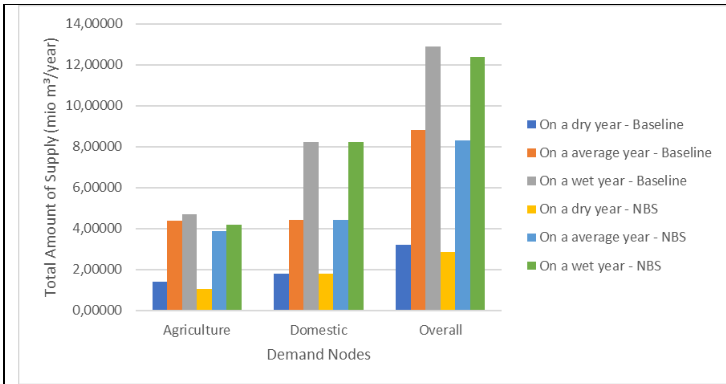


Figure 25: Total amount of supply according to Baseline and NBS scenarios in Koiliaris

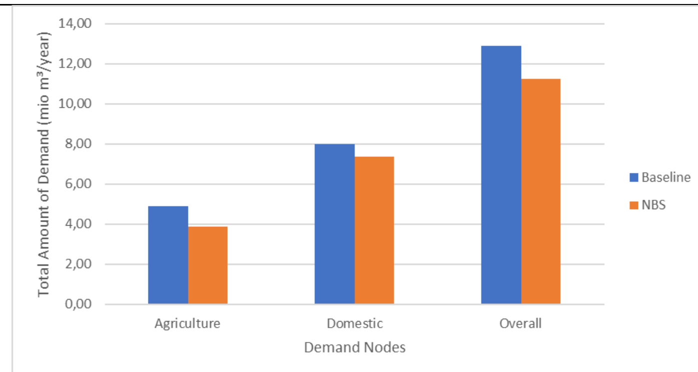


Figure 26: Total amount of demand according to Baseline and NBS scenarios in Koiliaris

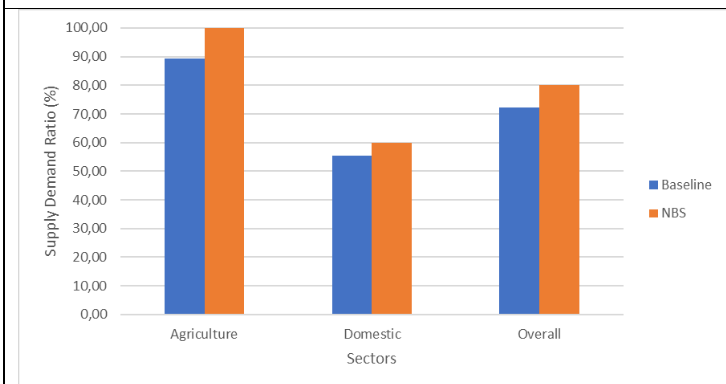


Figure 27: Supply demand ratio according to Baseline and NBS scenarios in Koiliaris

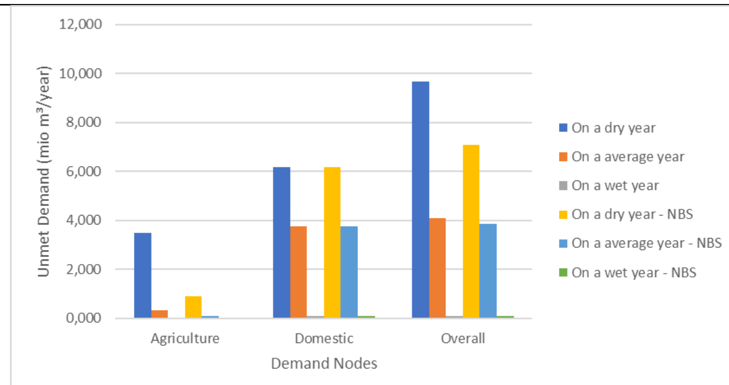


Figure 28: Total unmet demand according to Baseline and NBS scenarios in Koiliaris

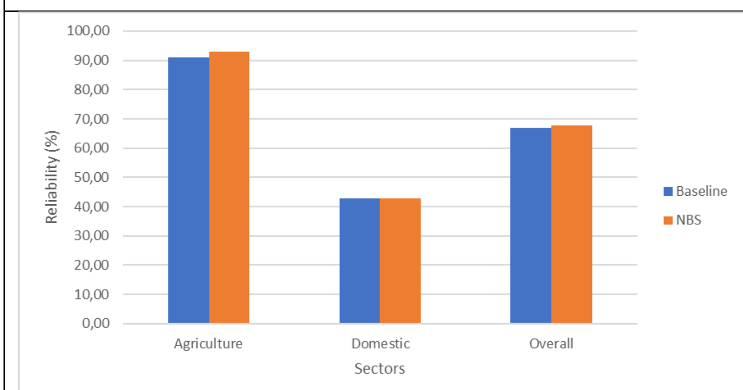


Figure 29: Reliability of source according to Baseline and NBS scenarios in Koiliaris

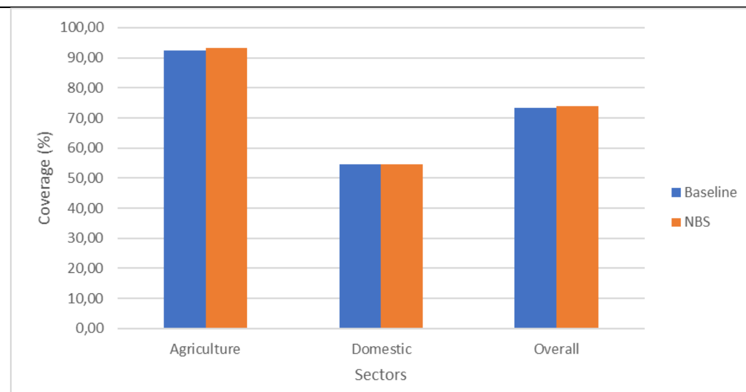


Figure 30: Coverage of demand according to Baseline and NBS scenarios in Koiliaris

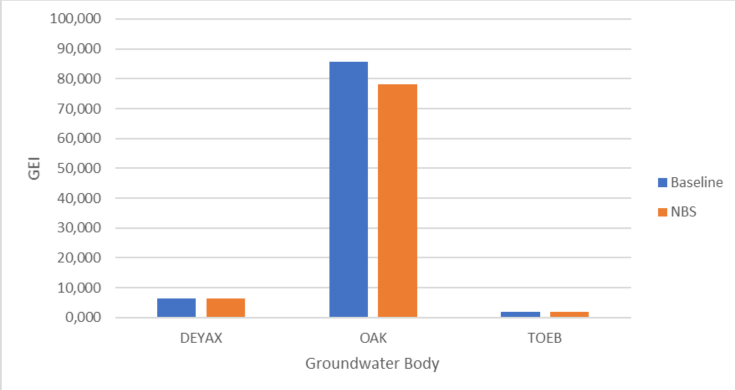


Figure 31: Water Exploitation Index according to Baseline and NBS scenarios in Koiliaris

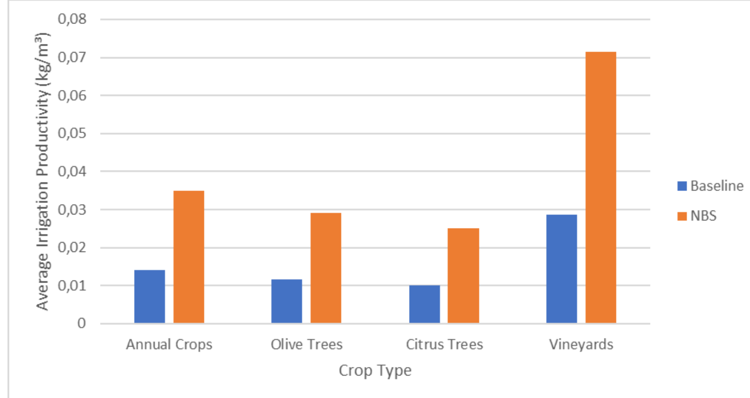


Figure 32: Average irrigation productivity according to Baseline and NBS scenarios in Koiliaris

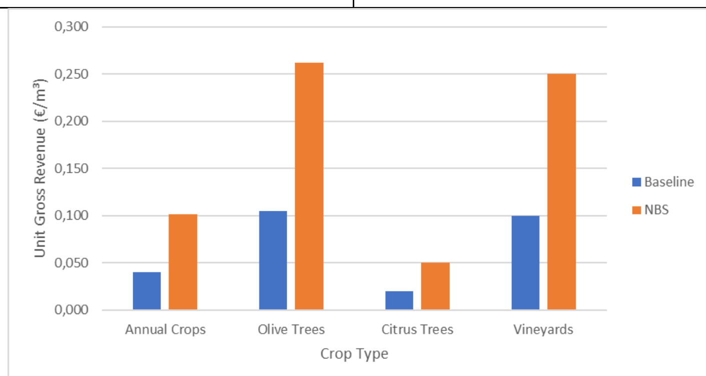


Figure 33: Unit gross revenue according to Baseline and NBS scenarios in Koiliaris

In Pinios (Greece), the pilot has implemented effective soil water management through irrigation scheduling and increased soil organic matter through mulching and mowing which increased the irrigation water efficiency by a total of %23.49 in the Agia pilot area and %22.37 in the Pinios Delta pilot area.

According to the results, the demand and supply of agricultural water decreased with the implementation of the NBSs (Figure 34, 35). The supply-demand ratio, reliability of the source, and coverage of demand remain unchanged since the pilot already had the maximum values for these indicators (Figure 36-38). The unmet instream flow demand decreased overall (Figure 43), and the WEI, and GEI had a significant drop in value for both Agia and Delta pilot areas (Figure 40-42). Finally, average irrigation productivity (Figure 43, 45) and unit gross revenue (Figure 44, 46) have increased due to reduced water demand.

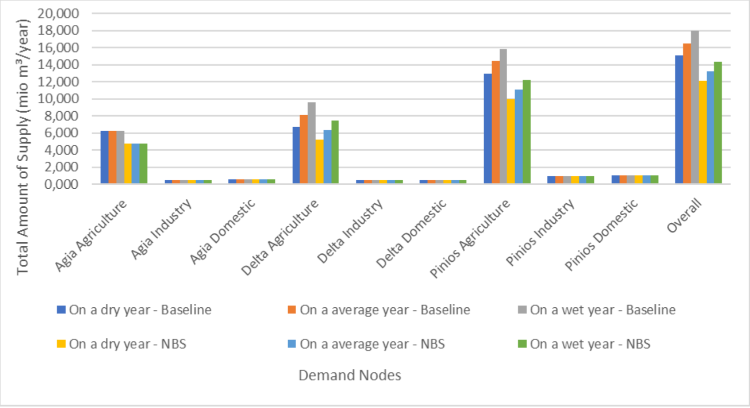


Figure 34: Total amount of supply according to Baseline and NBS scenarios in Pinios

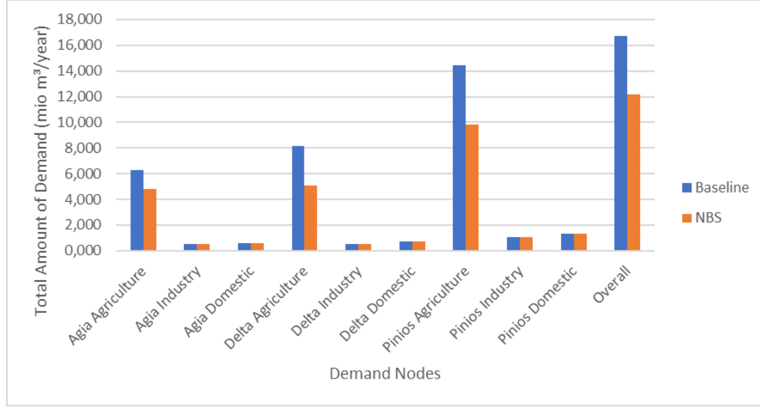


Figure 35: Total amount of demand according to Baseline and NBS scenarios i Pinios

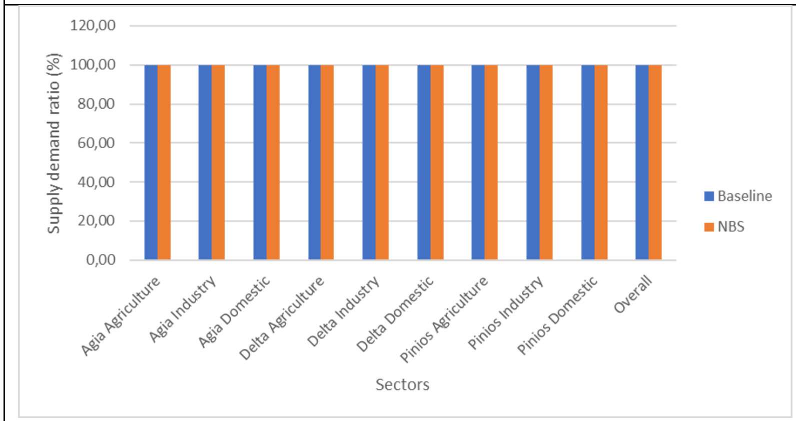


Figure 36: Supply demand ratio according to Baseline and NBS scenarios in Pinios

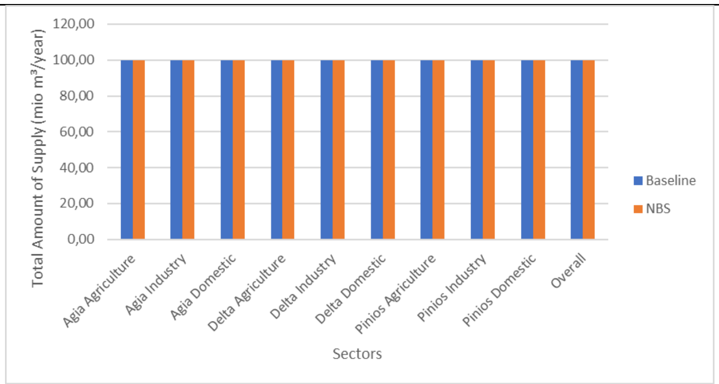


Figure 37: Reliability of source according to Baseline and NBS scenarios in Pinios

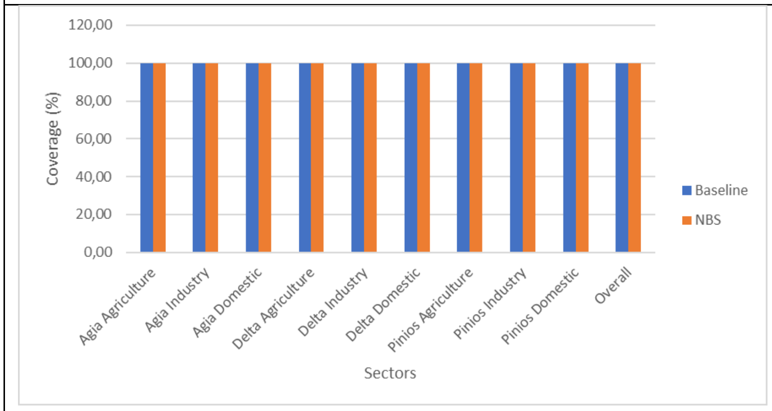


Figure 38: Coverage of demand according to Baseline and NBS scenarios in Pinios

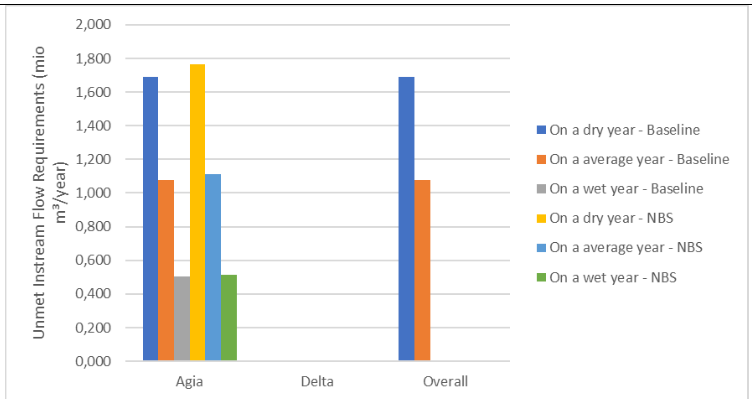


Figure 39: Unmet Instream flow demand according to Baseline and NBS scenarios in Pinios

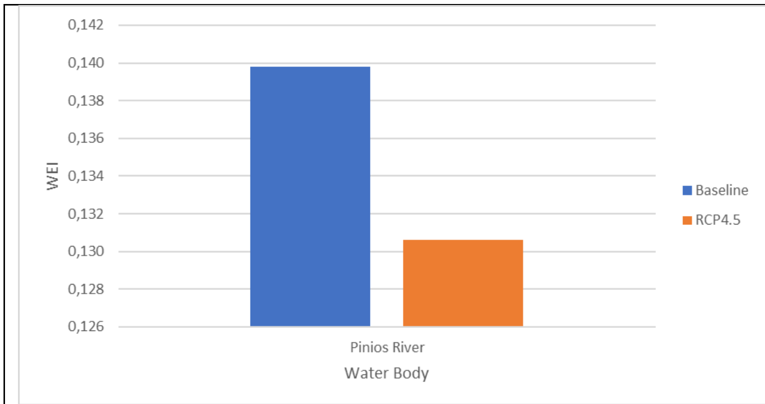


Figure 40: Water Exploitation Index according to Baseline and NBS scenarios in Pinios

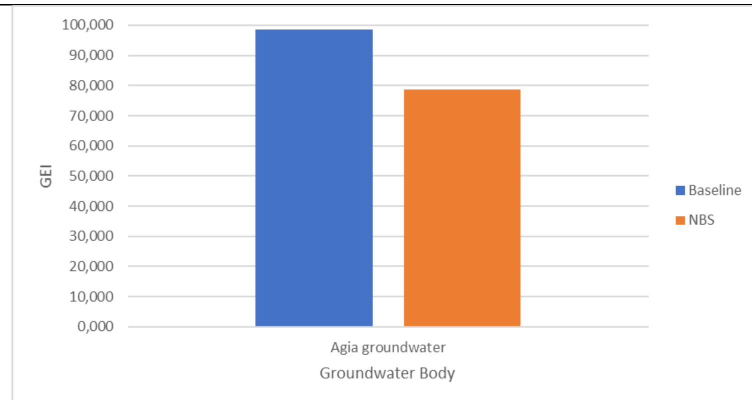


Figure 41: Groundwater Exploitation Index according to Baseline and NBS scenarios in Agia pilot area

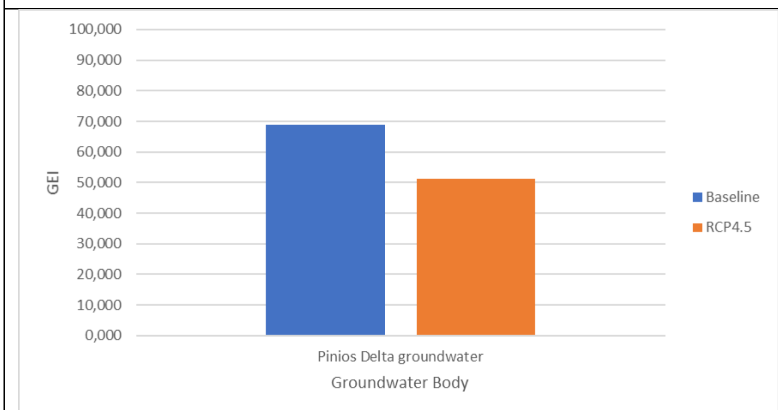


Figure 42: Groundwater Exploitation Index according to Baseline and NBS scenarios in Pinios Delta pilot area

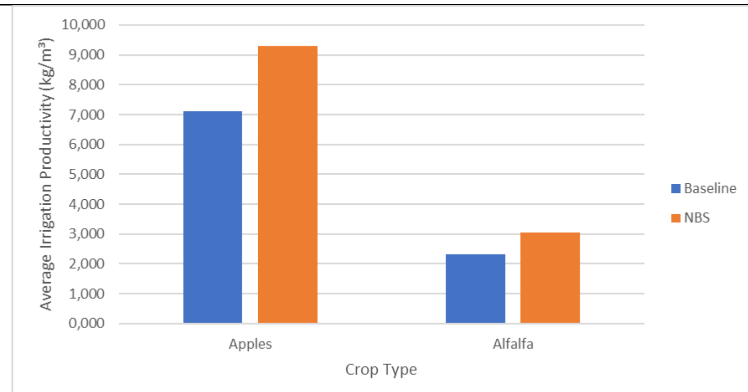


Figure 43: Average irrigation productivity according to Baseline and NBS scenarios in Agia pilot

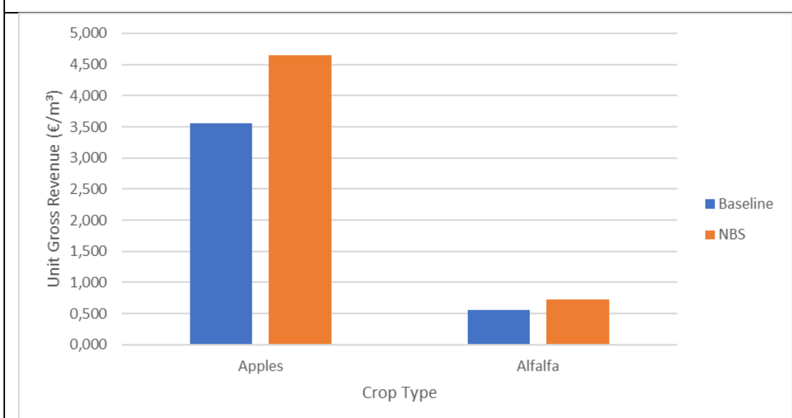


Figure 44: Unit gross revenue according to Baseline and NBS scenarios in Agia pilot

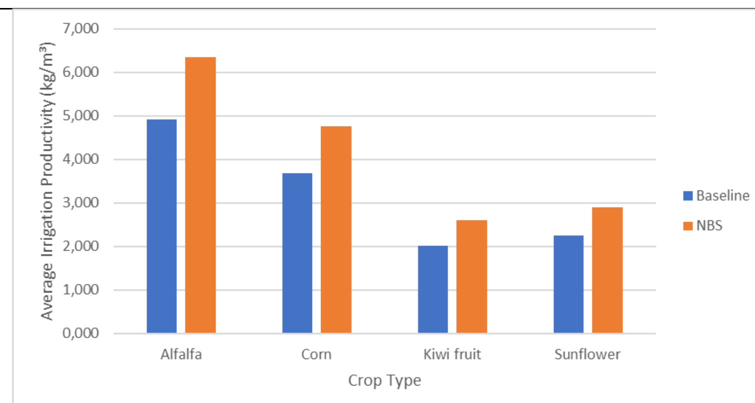


Figure 45: Average irrigation productivity according to Baseline and NBS scenarios in Pinios Delta pilot area

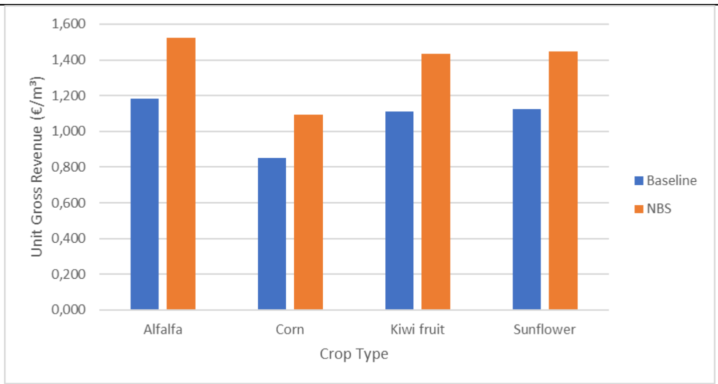


Figure 46: Unit gross revenue according to Baseline and NBS scenarios in Pinios Delta pilot area

In Tarquinia (Italy), the pilot has chosen the implementation of crop rotation and organic manure practices as possible NBS to be realized in the pilot area which was to estimate to increase the irrigation water efficiency by a total of %65 and the crop production by a %70. The pilot has also chosen floodplain restoration and management practices to be realized in the future.

The Italian pilot showcases a dramatic decrease in demand and supply of water since the main socio-economic activity in the pilot is agriculture (Figure 47, 48). The implementation of NBSs causes supply-demand ratio, reliability of source and coverage of demand to maximize up to %100 (Figures 49, 51, 52) and nullify the unmet demand (Figure 50). WEI in the pilot has also decreased considerably due to the lower agricultural water demands (Figure 53). Lastly, average irrigation productivity (Figure 54) and unit gross revenue (Figure 55) have increased due to reduced water demand and increased crop production.

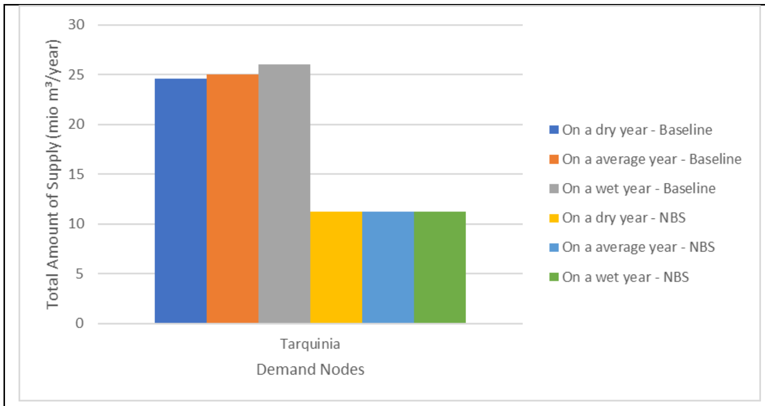


Figure 47: Total amount of supply according to Baseline and NBS scenarios in Tarquinia

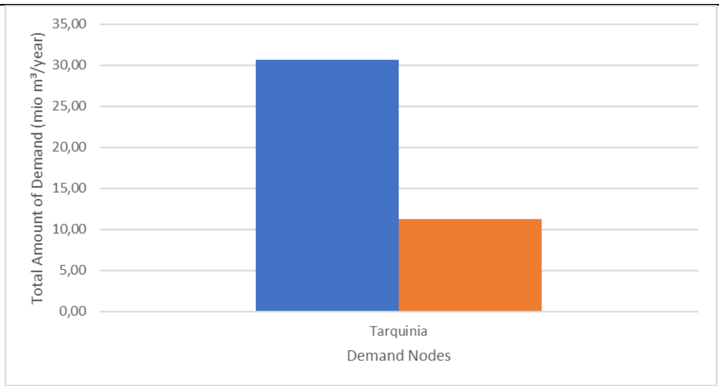


Figure 48: Total amount of demand according to Baseline and NBS scenarios in Tarquinia

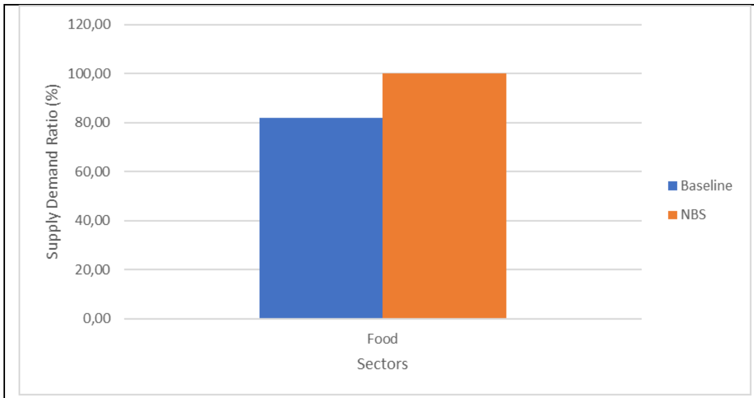


Figure 49: Supply demand ratio according to Baseline and NBS scenarios in Tarquinia

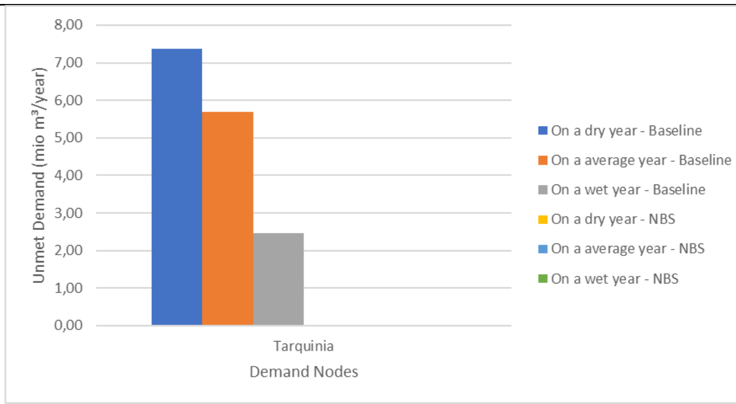


Figure 50: Total unmet demand according to Baseline and NBS scenarios in Tarquinia

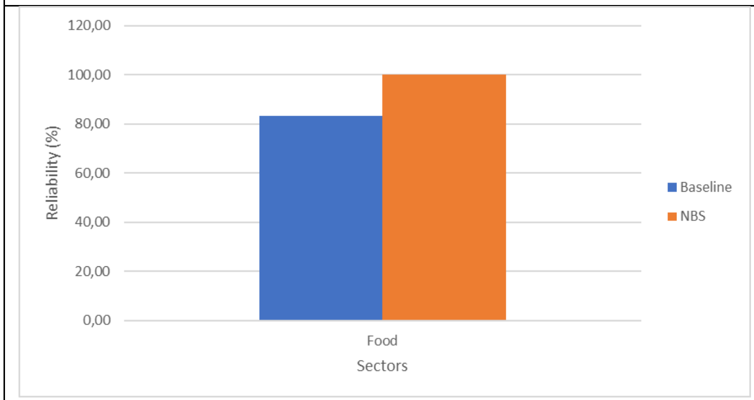


Figure 51: Reliability of source according to Baseline and NBS scenarios in Tarquinia

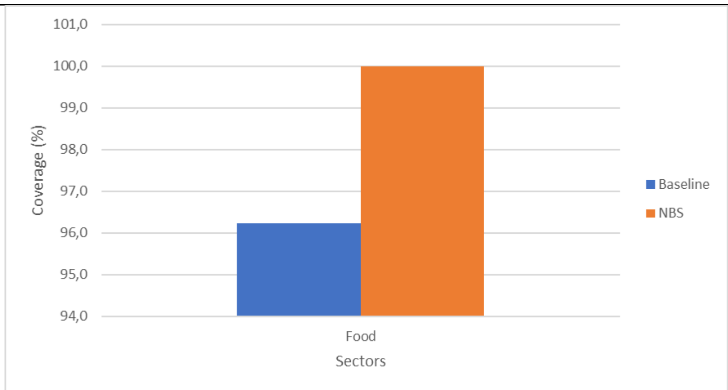


Figure 52: Coverage of demand according to Baseline and NBS scenarios in Tarquinia

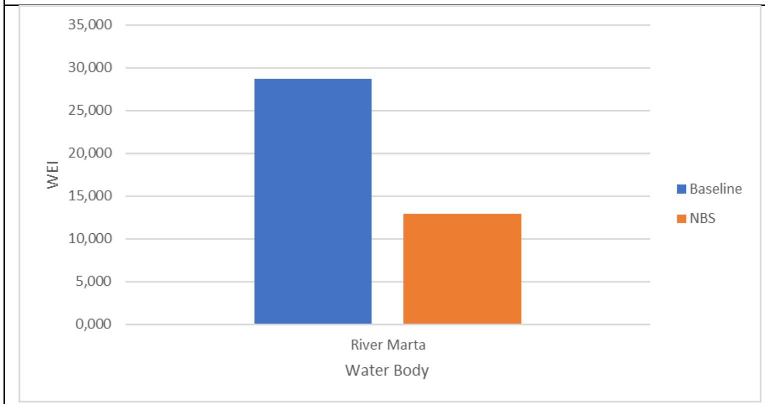


Figure 53: Water Exploitation Index according to Baseline and NBS scenarios in Tarquinia

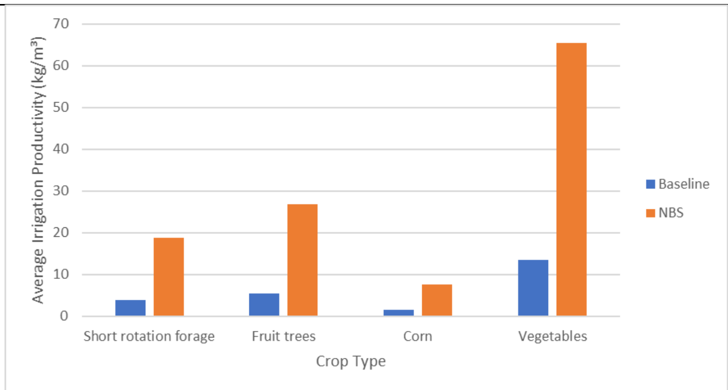


Figure 54: Average irrigation productivity according to Baseline and NBS scenarios in Tarquinia

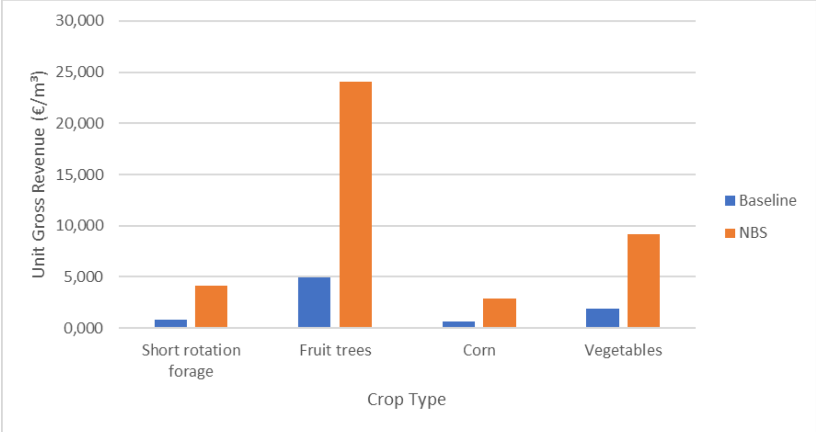


Figure 55: Unit gross revenue according to Baseline and NBS scenarios in Tarquinia

In Menemen (Turkey), the pilot has implemented intercropping and microbial fertilizer applications which were reported to have no significant impact on irrigation water efficiency or crop production.

4. Conclusions

Sustainable land management requires the maximization of the efficacy of soil ecosystem functions (and the related services) as well as the minimization of soil threats. Soil ecosystem functions include biomass production, carbon and nutrient sequestration, water filtration and transformation and biodiversity. Whereas soil threats include loss of soil carbon and nutrients, loss of biodiversity, erosion and soil compaction (Nikolaidis, 2011). In addition, sustainable land management has to be considered in terms of optimizing the WEF Nexus necessitating the use of hydrologic water allocation and geochemical models that assess not only the WEF Nexus, but also soil ecosystem functions and threats.

In this research, different NBS (terraces, riparian forest, livestock management and agro ecological practices etc) were assessed in terms of their impact to WEF Nexus. All NBS can directly or indirectly improve soil ecosystem functions and reduce soil threats. The NBS of terraces and riparian forest affect soil erosion. Specifically, terraces can reduce the sediment load up to 95%, riparian forest implementation can reduce this load up to 93%, while a combination of these NBS can reduce it up to 97%. Livestock management has impact on soil and water quality by reducing the nitrate levels at about 19%. The NBS of agroecological practices impact biomass production, carbon and nutrient sequestration, soil structure and geochemistry. The impact of agroecological practices on the plant-water-soil ecosystem and the resulting ecosystem services derived from such management practices were assessed with the 1D-ICZ model. Agroecological practices were shown to increase the organic carbon sequestered in the soil, and increase the WSA which are linked directly to soil health and fertility while maintaining a healthy biomass production. The below ground C sequestration is almost 6 times higher than the above ground plant production indicating the importance of soil carbon amendments in mitigating the impacts of climate change. In addition, the results of soil fractionation suggest that this carbon is fairly stable with a very long turnover time since more than 80% of it is in the particulate form. Finally, the leaching of the chemicals TOC, TN, PO_4-P and K to groundwater calculated to be 1.3, 14.6, 2.2, and 7.1 g/m^2 respectively which is only a small fraction of the total loads to the system. The water allocation modelling results presented also a significant impact on irrigation water efficiency and crop production, after applying NBS in the different pilots. Specifically, deep tillage, crop rotation, and organic manure practices increased the irrigation water efficiency up to a total of 70% and crop production up to a total of 95%. A reduction of irrigation based on the needs of the plants increased the irrigation water efficiency by a total of %60. Soil water management through irrigation scheduling and increased soil organic matter through mulching and mowing increased the irrigation water efficiency up to 23.5%. Intercropping and microbial fertilizer applications were shown to have no significant impact on irrigation water efficiency or crop production.

In addition to the quantitative results that were obtained through modelling for the impact of NBS on ecosystem services, there are also benefits and co-benefits that are derived from these actions on the WEF Nexus. A series of benefits and co-benefits related to water, ecosystem and food include erosion control, flood mitigation, climate resilience and regulation, carbon sequestration and nutrient cycling, increase in quantity and quality of food production etc.

The hydrologic and ecosystem models used in this work were able to quantify the direct impact of NBS and assess their effectiveness. The models were shown to be capable of simulating successfully the ecosystem services derived from the NBS application. This work showed that modeling tools as such as those used in this study can be used for the optimization of the WEF Nexus and thus for the evaluation of the effectiveness of different NBS scenarios.

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6. APPENDIX

MANUAL FOR NBS IMPLEMENTATION

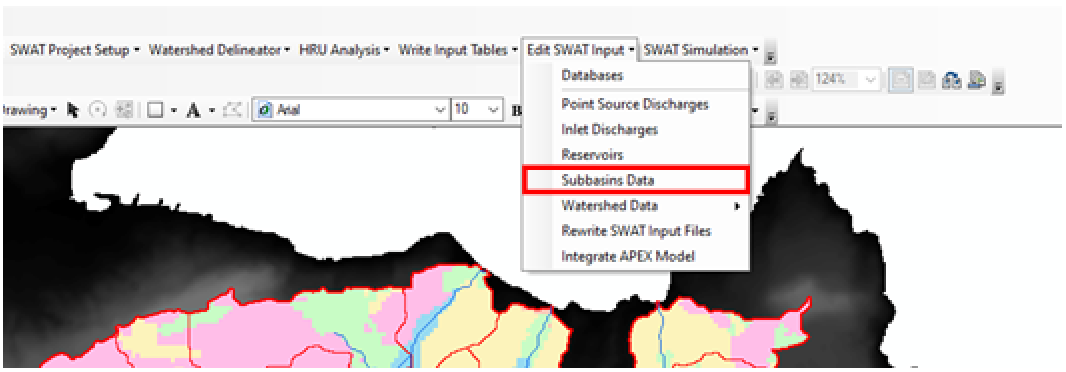
(TERRACING & RIPARIAN FOREST & LIVESTOCK ACTIVITY)

Technical University of Crete

After completing the modeling of hydrology and nitrates, which is described in the paper" Sediment Transport in the Koiliaris River of Crete" the application of Nature-Based Solutions (NBS) follows. The process of implementing NBS is described below.

01 EDIT SWAT INPUT MENU

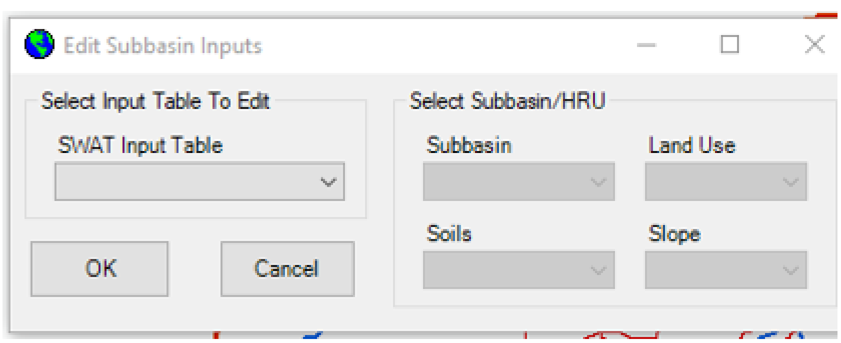
Under the **Edit SWAT Input** menu, click the Subbasins Data button.



02 EDIT SWAT INPUT WINDOW

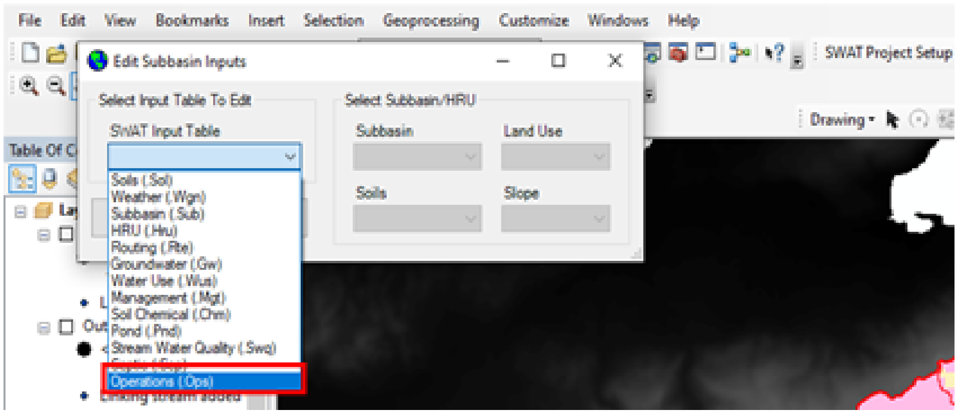
The **Edit SWAT Input** window will appear. This tool is divided into the following sections:

- Select Input Table To Edit
- Select Subbasin/HRU



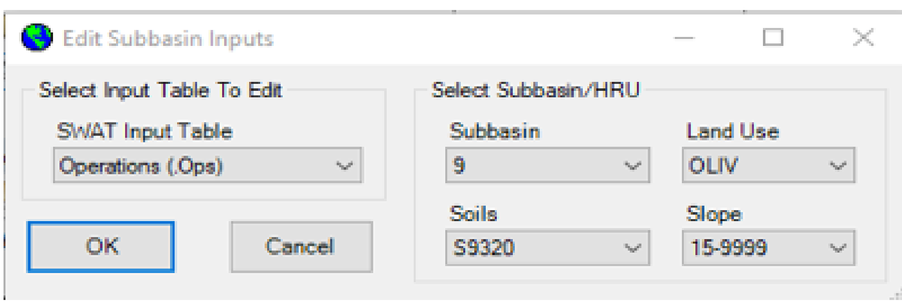
03 SELECT INPUT TABLE TO EDIT WINDOW

In the Select Input Table To Edit section, the user must select the appropriate SWAT Input Table. The appropriate table concerning the implementation of NBS is the "operations (Ops)" table.



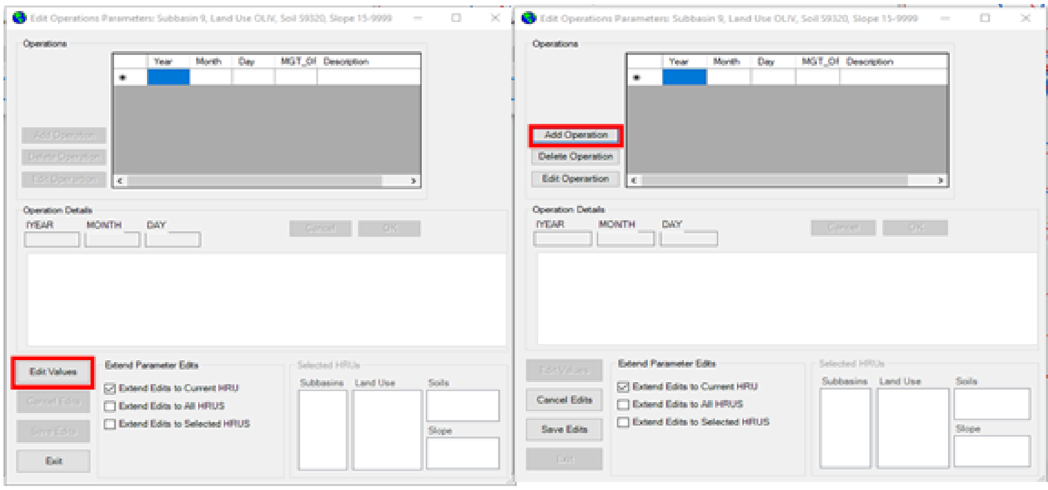
04 SELECT SUBBASIN/HRU WINDOW

In the Select Subbasin/HRU section, the user needs to select the HRU in which want to implement NBS. The HRU will be determined by choosing the Subbasin, Land Use, Soils and Slope.



05 INPUT OPERATION

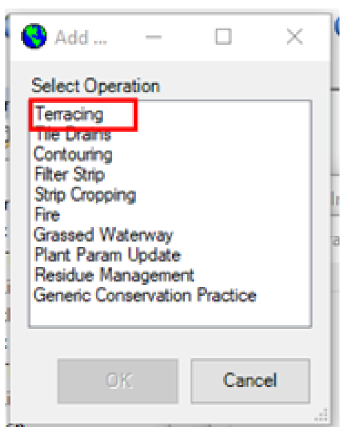
A new window will pop up. To input an operation, first click on the "Edit Values" button and then select "Add operation."



06 SELECT OPERATION

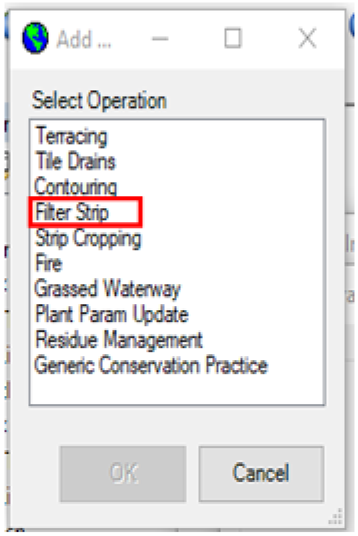
A. Terracing

In this step we are going to select the operation we want. In this case “Terracing” is selected.



B. Riparian Forest

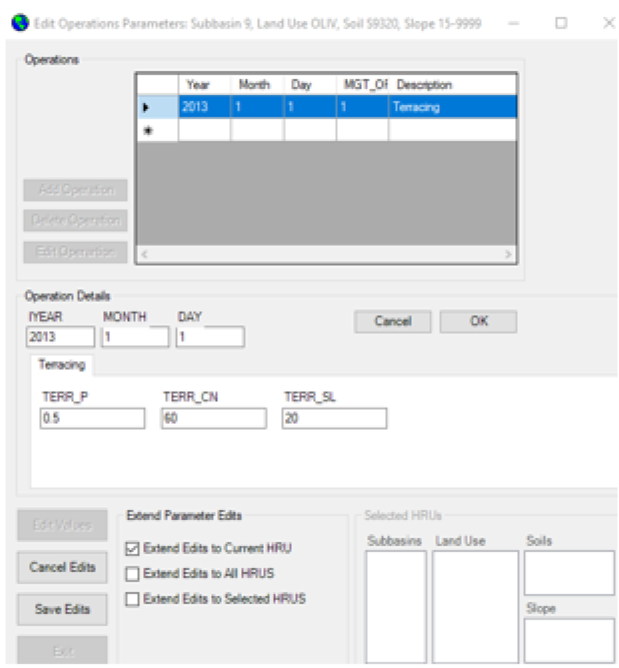
To create riparian forest, we are going to select the “Filter Strip.”



07 OPERATION DETAILS

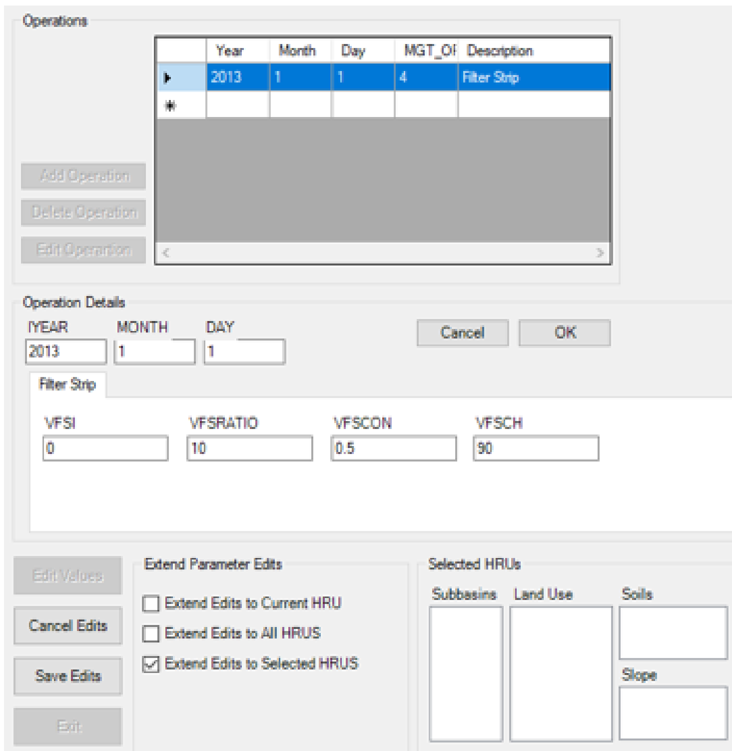
A. Terracing

In this window, we input the characteristics of Terracing. More details about the values are described in the Theoretical documentation (version 2009) of Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R., & King, K. W. (2011) in the Soil and Water Assessment Tool.



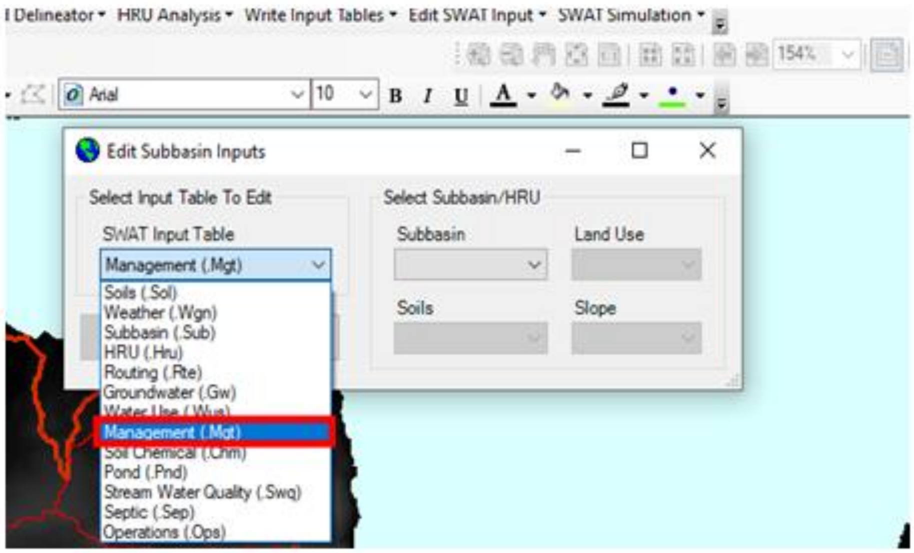
B. Riparian Forest

In this window, we input the characteristics of Filter Strip. More details about the values are described in the Theoretical documentation (version 2009) of Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R., & King, K. W. (2011) in the Soil and Water Assessment Tool.



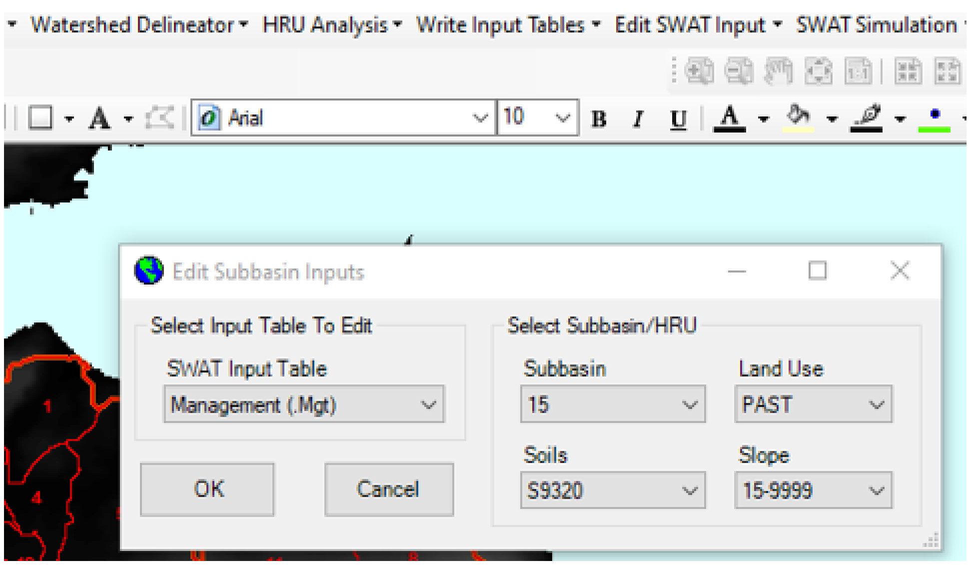
To implement established livestock farming, that is, to remove the presence of sheep/goats from grazing areas in mountainous regions, we will go back to step 3 and choose the "Management (.Mgt) table" as shown below.

08 SELECT INPUT TABLE TO EDIT



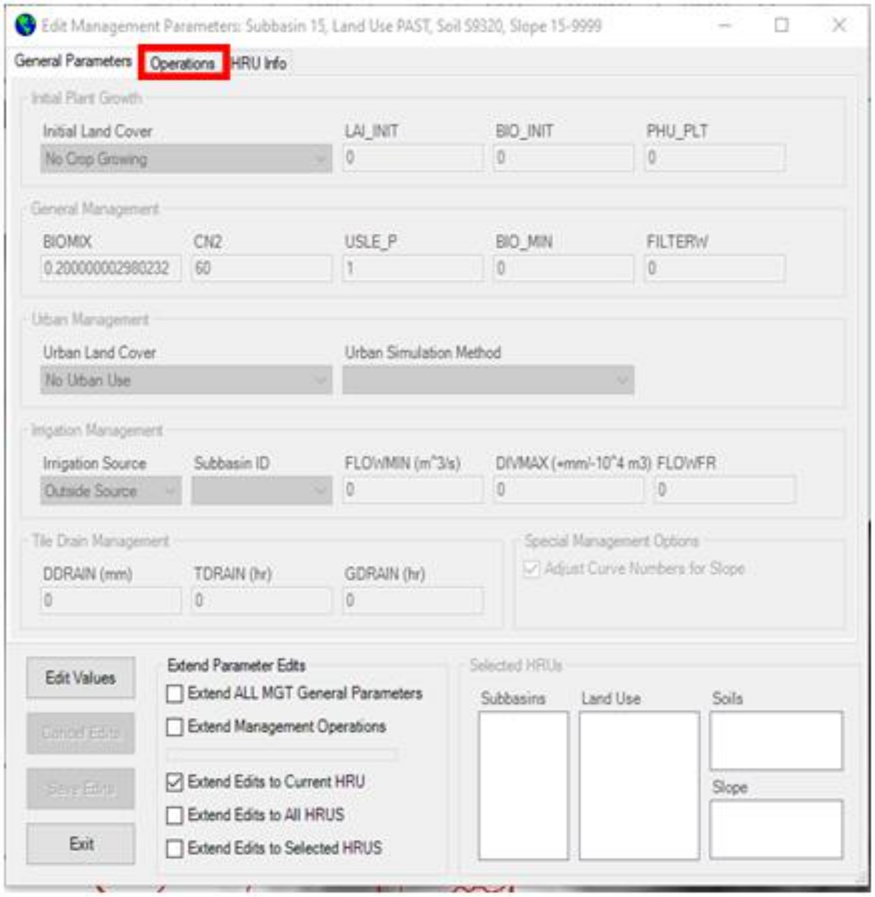
09 SELECT SUBBASIN/HRU WINDOW

In the Select Subbasin/HRU section, the user needs to select the HRU in which want to remove the presence of sheep/goats. The HRU will be determined by choosing the Subbasin, Land Use, Soils and Slope.



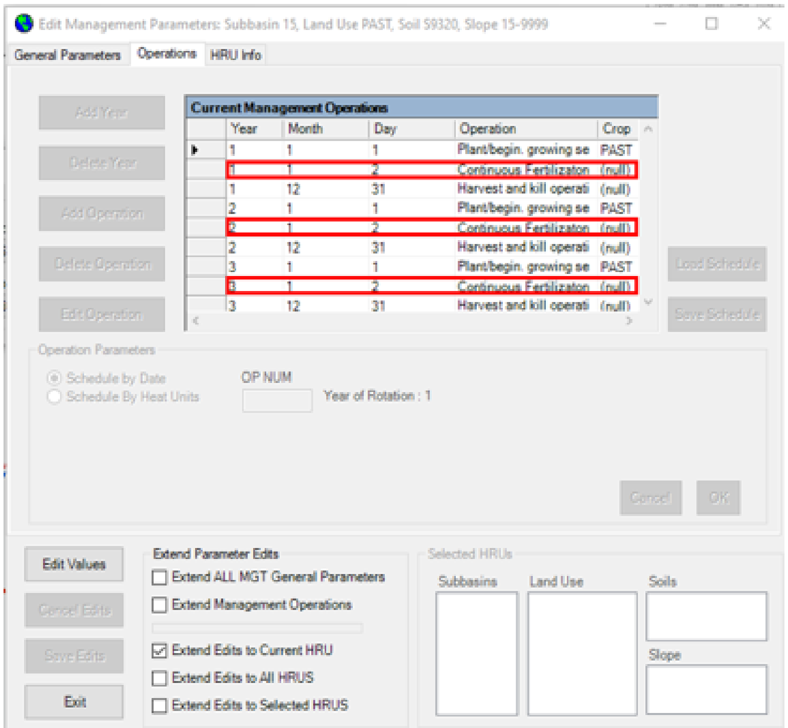
10 EDIT MANAGEMENT PARAMETERS

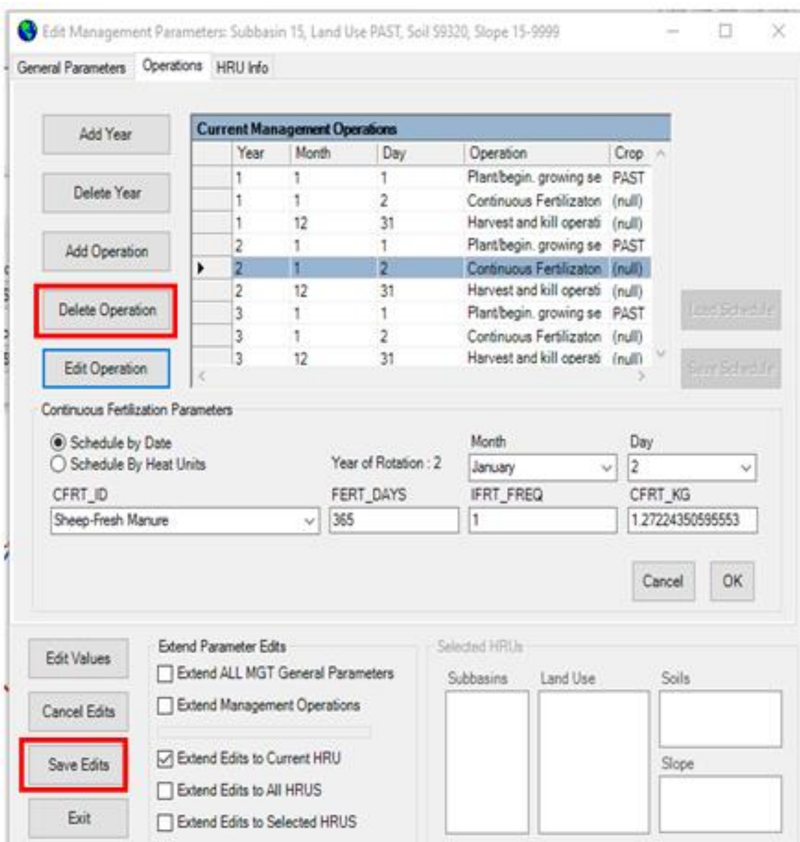
In pop up window which concerns the parameters of management, we select the tab "operations."



11 SELECT SUBBASIN/HRU WINDOW

At this step, we delete the existing processes that indicate the presence of sheep/goats. After making sure that the "continuous fertilization"refers to manure, we deleted the operation. In the second figure of this step presents information about sheep/goats' fertilization.


Edit Management Parameters: Subbasin 15, Land Use PAST, Soil S9320, Slope 15-9999
General Parameters
Operations
HRU Info
Add Year
Delete Year
Add Operation
Delete Operation
Edit Operation
Current Management Operations
Year
Month
Day
Operation
Crop
Plant/begin. growing se
Continuous Fertilizaton
Harvest and kill operati
PAST
(null)
Load Schedule
Save Schedule
Operation Parameters
Schedule by Date
Schedule By Heat Units
OP NUM
Year of Rotation : 1
Cancel
OK
Edit Values
Cancel Edits
Save Edits
Exit
Extend Parameter Edits
Extend ALL MGT General Parameters
Extend Management Operations
Extend Edits to Current HRU
Extend Edits to All HRUS
Extend Edits to Selected HRUS
Selected HRUs
Subbasins
Land Use
Soils
Slope


Edit Management Parameters: Subbasin 15, Land Use PAST, Soil S9320, Slope 15-9999
General Parameters
Operations
HRU Info
Add Year
Delete Year
Add Operation
Delete Operation
Edit Operation
Current Management Operations
Year
Month
Day
Operation
Crop
Plant/begin. growing se
Continuous Fertilizaton
Harvest and kill operati
PAST
(null)
Load Schedule
Save Schedule
Continuous Fertilization Parameters
Schedule by Date
Schedule By Heat Units
Year of Rotation : 2
Month
January
Day
2
CFRT_ID
Sheep-Fresh Manure
FERT_DAYS
365
IFRT_FREQ
1
CFRT_KG
1.27224350595553
Cancel
OK
Edit Values
Cancel Edits
Save Edits
Exit
Extend Parameter Edits
Extend ALL MGT General Parameters
Extend Management Operations
Extend Edits to Current HRU
Extend Edits to All HRUS
Extend Edits to Selected HRUS
Selected HRUs
Subbasins
Land Use
Soils
Slope