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Enhancing LULC scenarios impact assessment in hydrological dynamics using participatory mapping protocols in semiarid regions

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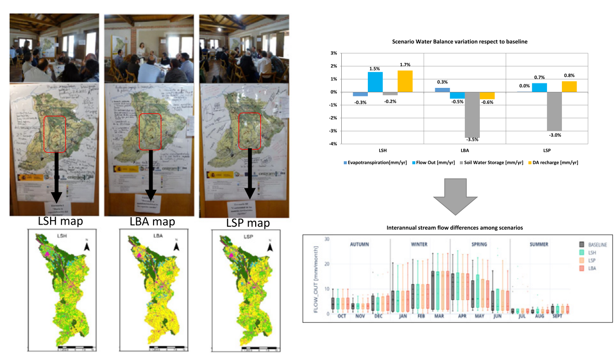
HIGHLIGHTS

- Static and dynamic LULC moderates buffer water dynamics on at local scales.
- Slight ET variations of +0.2% can affect ten times changes in semiarid streamflow.
- Annual aquifer recharge rises up to +1.7% when allocating specific natural covers.
- The land-sharing scenario may rise water availability in semiarid regions.

GRAPHICAL ABSTRACT



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ABSTRACT

Land use and land cover (LULC) scenarios in rural catchment hydrology are crucial to describe the effects of future water dynamics. However, there is a lack of understanding of the effectiveness of including static land covers at the subbasin level to provide inter-annual stability in changing the different water balance components. We developed a step-by-step mapping protocol to extend and enrich the hydrological assessment of future LULC scenarios defined through participatory stakeholder involvement. This novelty included specific allocation of static and dynamic LULC change among the scenarios and then compared the change of water dynamics to the current situation. For this, we quantified the LULC impact on the components of the water balance from three contrasting participatory scenarios implemented with the SWAT model in a rural basin in central Spain. The Land-sharing scenario (LSH) had the highest percentage of permanent grassland and shrubs and no increase of irrigated land compared to baseline. The land-sparing scenario (LSP) intensified agricultural land use close to urban areas, and the land balance scenario (LBA) was intermediate. The LSH increased the aquifer recharge by +1.7% and streamflow by +1.5%, while evapotranspiration and soil water storage decreased by -0.2%. In contrast, the LBA decreased in the riverine flux of -0.5%, an aquifer recharge of -0.6%, a soil water storage of -3.5%, and an evapotranspiration rate of +0.3%. Thus, LSH revealed that the allocation of permanent land cover such as grassland could buffer water dynamics, suggesting that dedicated planning and allocation of permanently vegetated LULC will favour land and water conservation.

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1. Introduction

Understanding the impact of land use and land cover (LULC) changes on water fluxes in semiarid regions can be challenging for rural agricultural catchments. At the same time, it may offer new opportunities for future hydrological management, which may ensure the sustainability of water-based ecosystem services (Netzer et al., 2019; Quintas-Soriano et al., 2016; Smiraglia et al., 2016; Vigerstol and Aukema, 2011). The current hydrological modelling developments have defined the technical routines and tools to assess the projected LULC changes. These changes are profoundly studied in time and space, but their quantification on water fluxes at local scales is scarce (Choukri et al., 2020; Gomes et al., 2020; Hérivaux et al., 2021; Näschen et al., 2019). Recent studies highlight the importance of participatory transcription of rules to define dynamic features for LULC scenario definition (Hérivaux et al., 2021; Kumar et al., 2020; Proswitz et al., 2021; Thompson et al., 2020), but at the moment, there remains in the field of LULC modelling to produce maps with management rules. The methods used to translate these rules into hydrological models are limited to punctual land management practices. Its combination with time sequences (e.g., crop rotations) is rarely included, and LULC scenarios act in a static state (Wagner et al., 2019). We apply a step-by-step mapping protocol to perform a detailed hydrological assessment using three participatory-based approaches of LULC scenarios to quantify the effect of LULC on subbasin water dynamics.

Hydrological modelling is widely used to understand and comprehend simultaneous spatial development processes in time (Booth et al., 2016; Veldkamp and Verburg, 2004). LULC management has influenced streamflow dynamics, the aquifer recharge, the amount of surface runoff, and return flow, among others, with different environmental implications (Gebremicael et al., 2019; Ni et al., 2021; Rust et al., 2014; Yan et al., 2016). These LULC changes are also responsible for the current water dynamics situation at different scales from global to subbasin. This situation is particularly relevant in semiarid regions where all the water balance components are sensitive to climate variations (Bangash et al., 2013). However, water managers need to guarantee the volumes to match agricultural water demands (Kumar and Singh, 2005; Lambin et al., 2001). There is an urgent need to understand the effect of individual actions focused on land LULC changes and management in a more multidisciplinary way (Chaplot, 2021; Garg et al., 2019; Minasny et al., 2017). In recent years, the hydrological assessment of LULC scenarios has gained importance to provide alternatives to alter future land developments and anticipate environmental effects at local scales (Aghsaei et al., 2020; Lacher et al., 2019; Salmoral et al., 2015).

LULC scenarios assessment of rural catchments is particularly relevant in semiarid regions since quantitative information about LULC change and land management timing can mitigate adverse water dynamics. Therefore, these scenarios not only describe the underlying effect of LULC changes in water resources, but their results also serve to communicate, stimulate, and enrich an open stakeholder debate for acting in local water planning (Ahmadisharaf et al., 2020; Mitter et al., 2019). When these LULC scenarios are integrated into hydrological modelling, the quantitative results can align sectoral interests and reduce water dynamics uncertainty of future land management. Scenario development is critical for ensuring consistency between scales, qualitative storylines, and future alternatives.

Several advances in the LULC scenarios for rural catchments have been reached in the last decades (Deng and Li, 2016; Ronfort et al., 2011). Enriching conceptually and methodologically its definition, but most of these have in common that the final product includes static LULC maps. The primary landscape processes (i.e., deforestation, forestation, urban development, agricultural intensification-extensification, and farm abandonment) are accompanied by specific actions usually defined annually and then replicated for each year in a static manner. The conventional methods to define LULC maps include cellular automata, Markovian predictive models, and scoring strategies (Behera et al., 2012; Gong et al., 2015; Hyandye and Martz, 2017; Kumar et al., 2021), but these are training over past trajectories to reproduce the future behaviour (Hamel et al., 2020). This approach is useful when past and future trajectories are aligned. The current situation presents continuity in time, which is the case for largely protected areas or with low rates of managed ecosystems (Nasiri et al., 2019; Ruben et al., 2020). However, in rural catchments, farmers' decisions drive dynamic changes impacting soil and water resources in the short and long term (Burt, 2001; Cerdà et al., 2018; von Lampe et al., 2014). Furthermore, participatory approaches have gained importance in different sectors (i.e., land use and energy) to develop social integrative long-term pathways (Bauer et al., 2017; Malek and Boerboom, 2015; Popp et al., 2017). These approaches integrate landscape features as land cover features. Participatory scenarios, however, allow to integrate qualitative storylines and socio-economic elements to build more plausible and reliable products such as LULC maps (Karner et al., 2019; Patel et al., 2007). These LULC maps also include land management operations that are key to promote accurate hydrological modelling.

The impact of past and current farm practices in catchment water dynamics has been significantly increasing since the '90s. Until now, the scope shaped the identification of individual landscape features and practices in catchments as crop percentage, specific tillage operations, crop rotation sequence that results in variations in some of the water balance components (Gobin et al., 2017; Lemaire et al., 2015; Louhichi et al., 2017). Research conducted by Zhang et al. (2008) reported changes in annual streamflow of -0.13 to -1.58 mm a^{-1} over the last four decades in catchments of the Loess Plateau in China. Ullrich and Volk (2009) found catchment variations of surface runoff (-13%), baseflow (6%), total water yield (-4%), varying management practices in spring barley in the State of Saxony in Central Germany, Chaplot et al. (2004) detected a streamflow diminution from 0.5 to 0.2 m^3/s following the conversion of corn-soybean rotations to grasslands. Luijten et al. (2000) indicated that the substitution of the traditional association of pasture, bush, woodland and annual crop to a forest, cropland or bare soils resulted in variations of stream water availability by -14, +5 and + 49%, respectively.

The individual effect of LULC change (i.e., forest to grassland or grassland to urban) on water dynamics has contributed significantly to understand catchment hydrology. However, more complex factors such as LULC change scenarios should be added to the current hydrological modelling exercises, including LULC change scenarios (Hively et al., 2009; Jones et al., 2017; Lee et al., 2016). The combined effect between landscape configuration and land practices can be derived from participatory LULC scenarios. It can render more realistic modelling results that represent high variability in time and space. Agricultural land management in small semiarid catchments usually occurs within a small window of time but does not occur at the same date. Another aspect is that the sequence of crops is not always the same; they follow trending crop sequences with minor deviations. Tillage operations usually follow cropping schedules and turns between farmers since they contract machinery communal services. Fallow land is critical to nutrient cycling and may promote soil water storage or contribute to contaminant transport into streams and aquifers (Schilling et al., 2008; Yilmaz et al., 2019). Land management and its dynamics can be included and assessed with hydrological modelling tools. The Soil Water Assessment Tool (SWAT), a widely used tool for hydrological modelling, allows a diverse land configuration and land operation for rural catchments and is among the most reliable tools for incorporating different catchment LULC dynamics (Mehdi et al., 2015; Wagner et al., 2019).

This research aims to develop a methodology for assessing the LULC change for assessing the land use/cover (LULC) change impact on a rural basin's water balance. The novelty of our approach lies in the combination of stakeholders' involvement, the mapping protocol to generate dynamic land use cover changes and spatio-temporal distributed hydrological modelling. We developed LULC scenarios with local stakeholders and incorporated their LULC practices and definitions for land management and dynamics such as crop rotations, tillage practices and soil cover management. We subsequently simulated the different water balance components with the Soil Water Assessment Tool (SWAT) and iterated this process together with the stakeholders. We tested the methodology on a sub-basin of Duero's River basin. In rural central Spain, extensive rainfed agriculture is the dominant economic activity (Moreno et al., 2010). The Duero's River basin is characterised by rainfed agricultural cultivation, but the region is seriously confronted with water scarcity (De Miguel et al., 2015; Mayor et al., 2015; Vicente Gonzalez et al., 2016). However, the agricultural practices identified during the last decade reveal that horticulture is an emerging sector developed in the mid/lowlands of Duero's River. DRBA (Duero's River Basin Authority), ITACyL (Agricultural Technological Institute of Castile and Leon) and MAPA (Ministry of Agriculture, Fisheries and Food of Spain) agree on this point. This expansion is due to increasing demand for horticultural products, making the sector attractive for farmers and implying environmental effects at the basin scale. Basin planners are therefore facing an increased social pressure to implement agricultural water use intensification in future river basin management plans.

2. Materials and methods

2.1. Study area

The sub-basin considered in this study is a surface water body in the midlands of Cega-Eresma-Adaja (CEA) system in Duero's River basin, Fig. 1. The sub-basin "*Arroyo de la Balisa*" (AdlB) comprises 242 km^2 and is part of Segovia province in North Central Spain. The sub-basin stream persists under unregulated regime inside the CEA system that is regulated by some reservoirs in the upwaters. In addition, the ecological status of sub-basin is deficient due to low IPS (Specific Pollution Sensitivity Index), a biological water quality indicator related to benthic organisms (CHD, 2015). The sub-basin is hilly, with an elevation range between 747 and 1011 m. The common soils are Luvisols, Fluvisols and Cambisols based on FAO soil classes(Nachtergaele et al., 2009), presenting moderate infiltration rates. The agro-climate is dominated by a Mediterranean sub-arid regime, highlighted by extreme dry summer and mean annual precipitation of 427 mm yr^{-1} (AEMET, 2013). In addition, the sub-basin is fundamentally bestowed to agriculture activity (70%), mainly used for rainfed cereal production (e.g. winter wheat and barley). Although irrigation is occasional, it is linked with a very high-water demand and intensive tillage and fertilization.

The landscape has been impacted in the area, and LULC changes dramatically shift agriculture into more dynamic arrays (Fornés et al., 2005; Pinilla, 2006; van Leeuwen et al., 2019). Because of this, the water resource quantification in the Duero River has decreased by -10.1% in the Spanish part of the basin (CHD, 2015), that is what has motivated the following river basin management plan 2022–2027, this situation can be more accentuated by analysing individual catchment with variations of -25% (CHD, 2015). Therefore, water availability is currently worrisome. This trend can be expected to be maintained for the next decade with the aggravation to face an emergent configuration of the future farming systems demands, including the horticulture boom.

2.2. Step-by-step protocol for hydrological assessment of LULC scenarios defined through a participatory exercise

Fig. 2 shows the workflow followed in assessing the impact in water fluxes because of LULC changes. This scheme comprises nine main steps: preprocessing data before the participatory exercise, mapping strategy, hydrological modelling set-up of the different models, and final water balance component analysis to compare different situations.

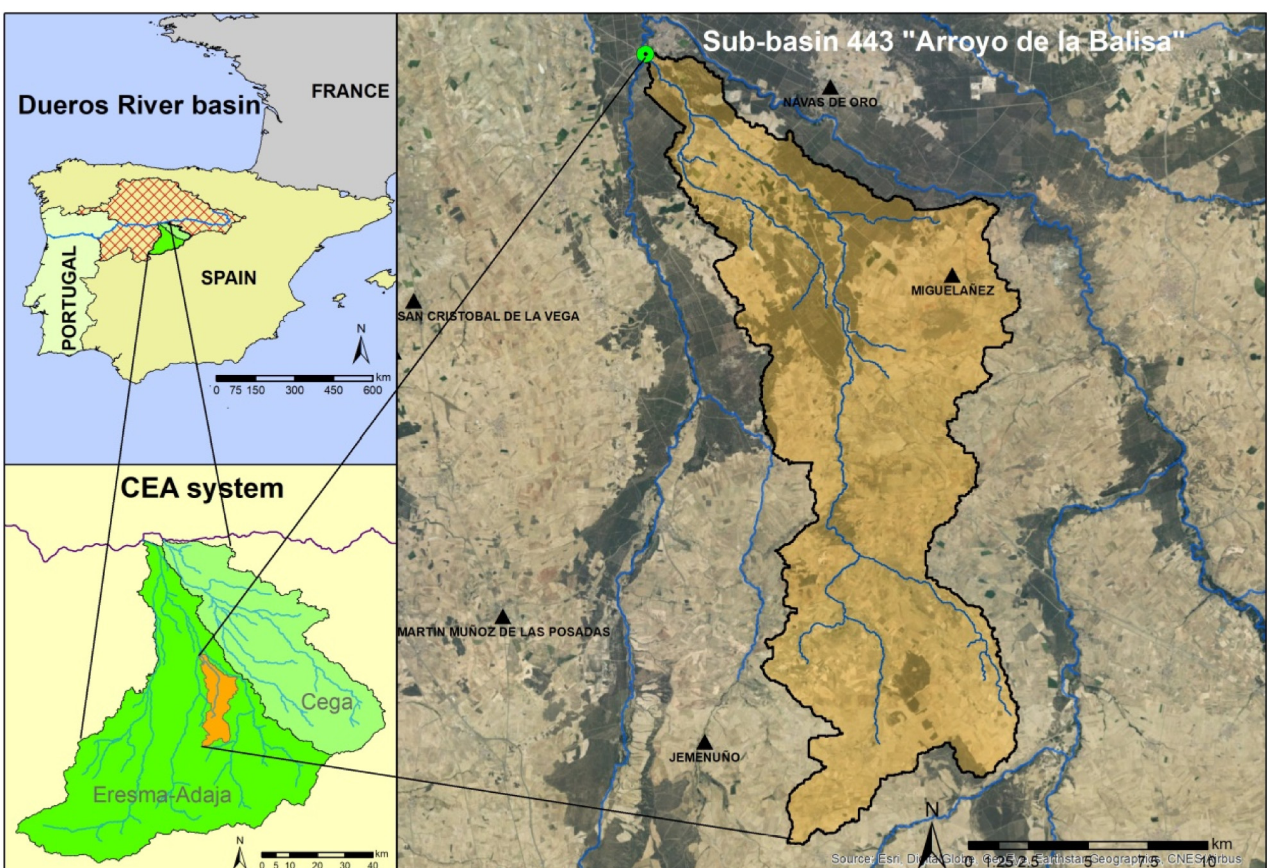

Fig. 1. Case study area, subbasin "Arroyo de la Balisa" (AdlB) in North Central Spain.

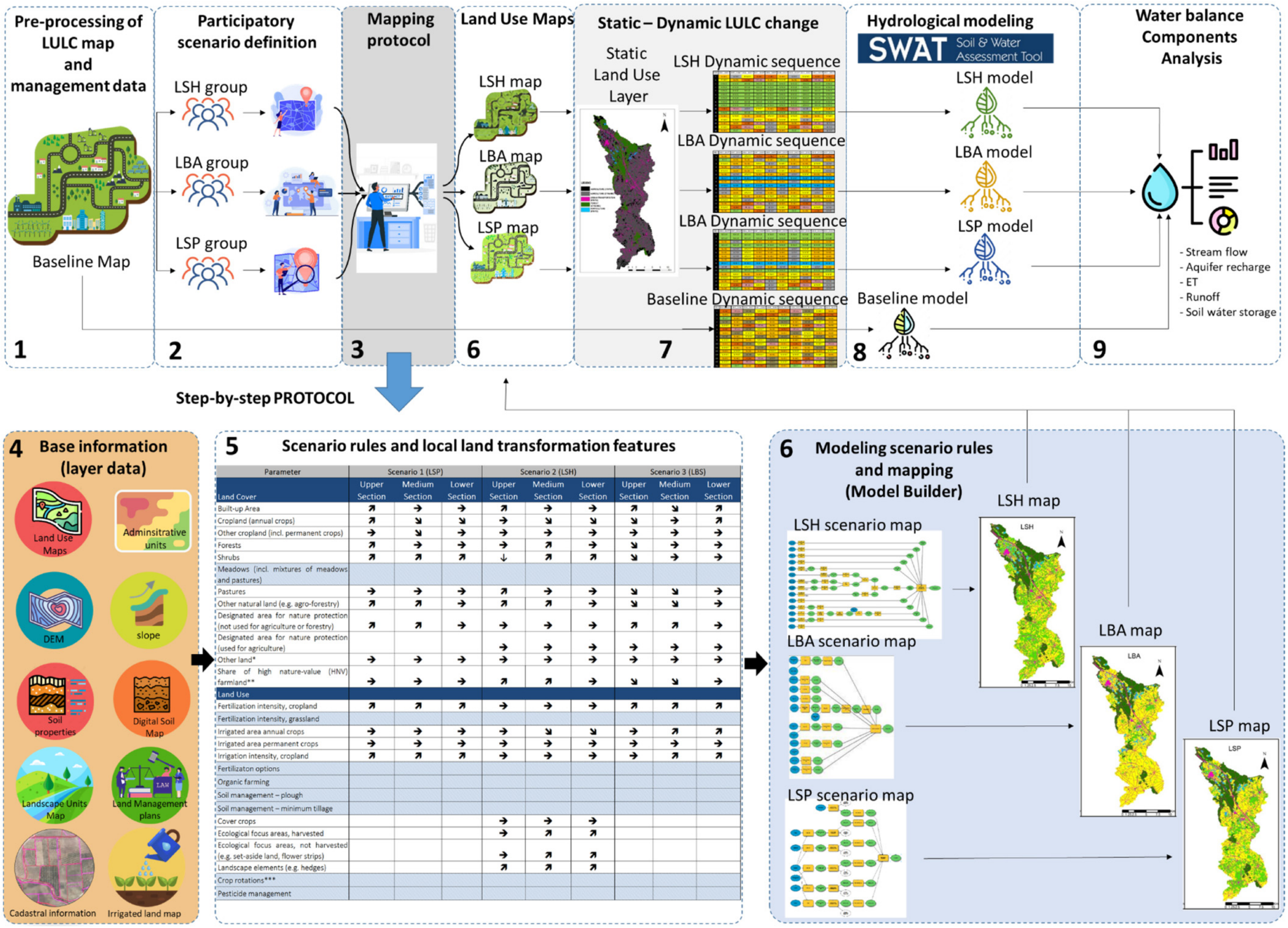

Fig. 2. Methodological framework for the analysis of the hydrological implications of LULC change for Land Sharing – LSH, Land Balance – LBA and Land Sparin – LSP scenarios. Details of Mapping protocol (step 3) show the integration of base information as data layers and local scenario rules to create LULC maps.

Step 1 of Fig. 2 represents the baseline situation in which a LULC map was settled to define the current catchment situation. Step 2 was the participatory exercise in which water-related stakeholders were met and selected to represent each scenario. Step 3 was central in translating data from the workshop into quantitative data and is the innovative central part of this study. Steps 4, 5 corresponds to a protocol of actions that bridge quantitative scenario rules and local transformation features, with base information as layer maps, to build modelling scenario rules in the model builder of ArcGIS to crate the final LULC maps. Steps 6 and 7 correspond to quantitative data as LULC maps per scenario with its corresponding LULC status (i.e., static and dynamic conditions) with setting up the conditions of LULC change for each hydrological model in SWAT (step 8). Step 9 represent the water balance components analysis to compare the current situation of the baseline model to the LSH, LBA and LSP scenarios.

2.2.1. Pre-processing of LULC map and management data

Prior to the participatory scenario definition, a LULC map was performed to allocate crop rotation and management operations. Then this was used for baseline model set-up since it represents properly the average distribution of LUs during the interval of analysis (Rivas-Tabares et al., 2019). To allocate temporal the LUs, specifically to identify crop rotation for the period 2004 to 2014, two sources of information were used: satellite images already classified by ITACyL for the period 2011-2014 (https://atlas.itacyl.es/descarga/); and data from a regional survey of JCyL (The Junta of Castile and Leon) for the period 2004 to 2010. As a result of overlapping the former data sources, a hybrid set of LU maps at a resolution of 20 m were defined for the period 2004-2011. This was conducted to represent the LU spatially matching the survey area for each land cover. In addition, cadastral maps were additionally used to improve the spatial matching of LULC time-series for the simulation period. The LU classes were defined in detail for agriculture (crops), forest, grassland, shrubs, urban-transportation and water.

The definitions of LU management include all human activities on a given system (Neitsch et al., 2002). In this case, the assessment of those activities was focused on cropland practices. The rotational crop patterns described by stakeholders were adjusted to a graphical template to facilitate the assignation of management information. This template facilitates the allocation of management rules from stakeholders and secondary sources, like surveys. The template is intuitive for the crop cycle and, at the same time, is in concordance with the hydrological year. However, this template is also flexible and could be adapted to other crop pattern cycles.

The template also identifies other farm practices, such as plantation dates, tillage, irrigation, fertiliser and pesticide application, intermediate cropping, harvesting dates, etc. Although the assigned dates are estimates due to variability of each year's weather conditions but fixed for modelling purposes. Once the template was completed with the crop pattern and its management, the modeller translates them into data input for modelling. However, the introduced values into the model assuming that operations for each crop occurs at the same date over the whole sub-basin. A summary of management practices by the crop is presented in Table 1.

Table 1
Summary of management practices by land use (LU) crop in Sub-Basin "*Arroyo de la Balisa*" (AdlB), Spain.

Land Use		Planting	Tillage		Fertilization			Harvest
Crop	SWAT Code	Date	Operation	Date	Date	N-P-K	Total (kg)	Date
Winter Wheat	WWHT	08-dic	Fallow	03-dic	12-oct	27-00-00	350	28-jul
			Field Cultivator Lt15ft	05-dic				
			Roller Packer Flat Roller	07-dic				
Barley	BARL	25-feb	Fallow	23-feb	24-feb	27-00-00	350	21-jul
Maize	CORN	01-abr	Subsoil Chisel Plow	10-abr	06-may	08-15-15	1000	15-sep
			Rotary Hoe	25-abr				
			Field Cultivator Lt15ft	25-may				
			Roller Packer Flat Roller	30-may				
Potato	POTA	16-abr	Spring Ploughing	05-abr	04-abr	08-15-15	1000	22-ago
			Field Cultivator Lt15ft	09-abr				
			Bedded disk-row	12-abr				
			Beet cultivator 8 row	14-abr				
Sugar beet	SGBT	01-mar	Spring Ploughing	20-feb	01-mar	27-00-00	1200	15-may
			Field Cultivator Lt15ft	27-feb				
			Disk Plow Lt23ft	28-feb				
Sunflower	SUNF	25-abr	Spring tooth Harrow Ge15ft	23-mar	22-mar	08-15-15	600	02-sep
Alfalfa	ALFA	01-oct	Fallow	04-oct	02-oct	00-20-20	200	05-may
								05-jun
								01-jul
								05-ago
								01-sep
								30-sep
Horticulture	HORT	03-mar	Fallow	02-mar	01-mar	Elem-N	500	01-ago
Aromatic herbs	AROM	15-feb	Fallow	02-mar	04-mar	Elem-N	500	01-ago
Peas	PEAS	15-nov	Fallow	14-feb	13-feb	Elem-N	300	01-jul
Canola	CANA	06-oct	Fallow	16-oct	17-oct	08-15-15	250	20-jul
Olives	OLIV	already planted	Spring Ploughing	02-mar	01-mar	Elem-N	250	15-oct
Vineyard	GRAP	already planted	Spring Ploughing	15-mar	13-abr	Elem-N	250	15-ago

2.2.2. Scenario definition

The LULC scenarios used in this research build on the participatory process developed in the TALE project (Towards multifunctional agricultural landscapes in Europe: Assessing and governing synergies between food production, biodiversity, and ecosystem services) (Volk and Hagemann, 2018). TALE's purpose was to include a debate on land sharing and land sparing into the reality of different European agricultural landscapes. This was asses by developing participatory agricultural scenarios, consistent with European policies (Common Agricultural Policy, Water Framework Directive, Birds and Habitat Directive) and global socio-economic drivers as determined by the IPCC Shared Socioeconomic Pathway, and explore quantitatively the ecosystem services synergies and trade-offs linked to different LU trajectories. The project involved five case studies, and AdlB sub-basin of CEA basin was one of the case studies (see Fig. 2). Thus, the LULC scenarios of this sub-basin build on the participatory exercise of the TALE project. The details of the scenario process are described in Hagemann et al. (2019), and the resulting scenarios are discussed in Karner et al. (2019). The LU scenarios represent contrasting visions about balancing regional agricultural development and the continuous provision of vital ecosystem services such as water supply and biodiversity conservation.

A participatory scenario approach was used to create the bridge between European LU narratives (Karner et al., 2019) and the local context in which LU decisions occur. Such an approach also allows

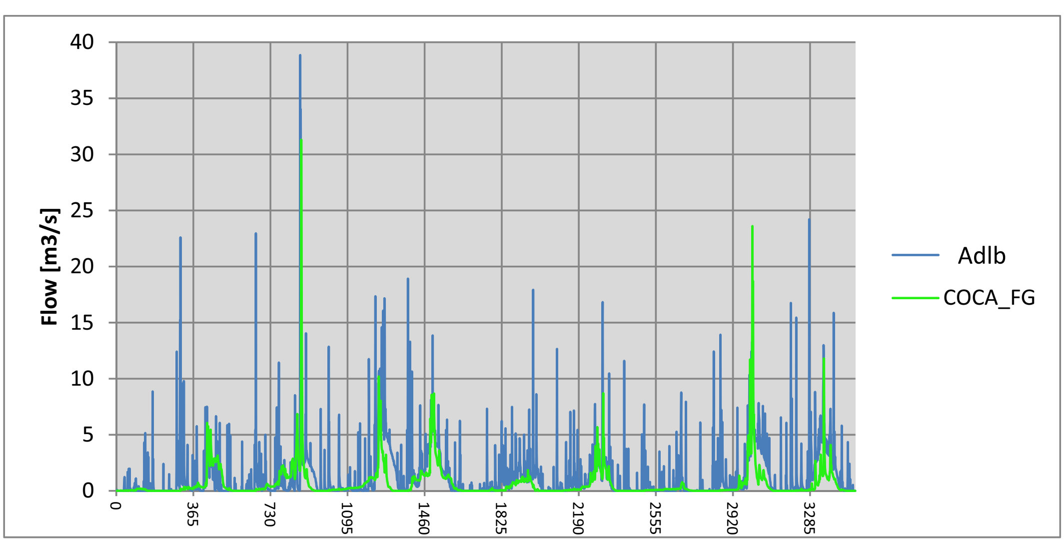

Fig. 3. Average daily stream flow discharge series comparison between Coca flow gauge (COCA_FG) and subbasin"*Arroyo de la Balisa*" (AdlB) flow gauge from Ceja-Eresma-Adaja (CEA) for the period from 2004 to 2014.

translating and simulating through modelling tools a more accurate water balance components quantification. The main purpose of the participatory scenarios is to translate narrative scenarios into a quantitative assessment of the LU scenario and assess the stakeholder perception for plausible future land use at the local context showing the contrasting results to current LU patterns. These scenarios were validated with actors before being used for hydrological simulation. Further details on the participatory scenario process, stakeholder composition group, narratives and outcomes are provided in the supplementary material Annex 1.

2.2.3. SWAT Modelling

The SWAT model was used to assess water budget differences from the three contrasting visions of agricultural development through LULC scenarios in the sub-basin AdlB of the CEA system. This assessment included the regime variation of the streamflow out and the deep aquifer recharge volume fluctuations. The model set-up, calibration and validation procedures were used from a previous SWAT model of the CEA system (Rivas-Tabares et al., 2019). The sub-basin AdlB was extracted from it to establish the baseline scenario. The outflow series of the CEA model were analysed to determine whether the flow from the Las Cogotas reservoir affects the flow series at the outlet of sub-basin AdlB. The Coca flow gauge values and CEA previous model results (Rivas-Tabares et al., 2019) were compared. In sub-basin AdlB, there was no reservoir effect on the outflow discharge series, Fig. 3. Therefore, the CEA model's calibration and validation parameters could safely be used to adjust the different LU scenario models (LSH, LBA and LSP).

Nonetheless, the definition of HRU during the modelling of LULC scenarios is crucial for its spatial representativeness. The HRUs are spatially and dimensionally different depending on LU, soils and slope. The

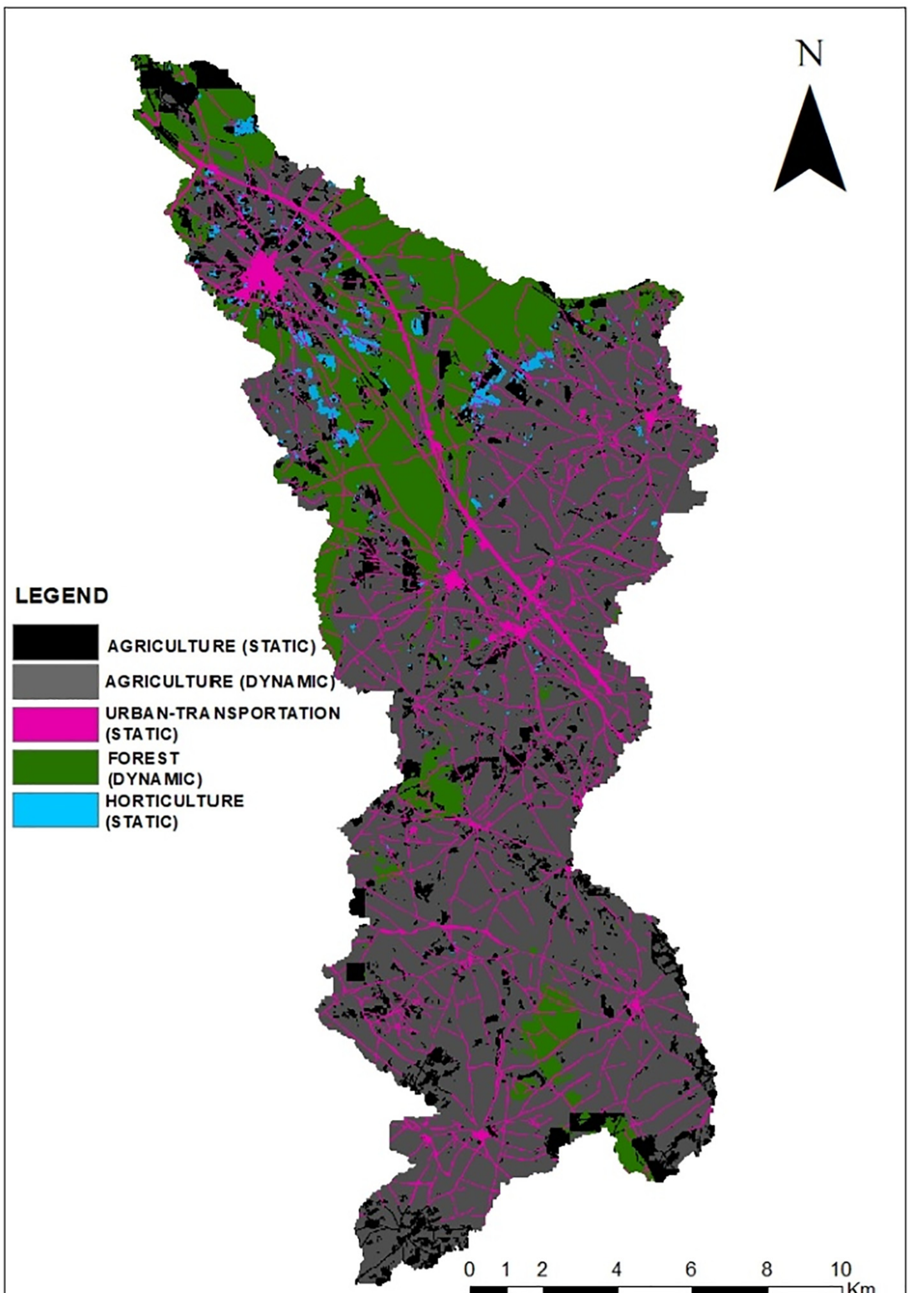

Fig. 4. Static and dynamic Hydrological Response Units (HRU) of subbasin "*Arroyo de la Balisa*" AdlB.

hydrologic implications of LULC change were evaluated against HRU spatial distribution. The HRUs bounds for this study are spatially coincident across all LU scenarios independent of crop and management schedule.

The baseline model was defined with 224 HRUs based on LU reference map for the simulation period. Considering the baseline model as a reference for HRU definition, the 224 HRUs polygons are common through the four models (Baseline, LSH, LBA and LSP). According to LU's, we classified the HRU condition, distinguishing between static and dynamic LULC change. Static HRUs are water bodies, transportation, urban, irrigated areas, and some forest patches. Most agricultural HRUs are dynamic. Crop rotations and crop management were assigned for each scenario. A group of 208 units was classified as static HRUs (49.4% of the total area) and represented polygons less than 100 ha each. The other complimentary 16 HRUs (dynamic) were bigger than 100 ha, Fig. 4. From the static HRUs (208), 192 HRUs were dedicated to agriculture in a fragmented mosaic pattern representing 10.4% of the area, the resting (16) static HRUs were assigned by the following: (4) for urban/transportation, (4) grassland and shrubs, (6) forest and (2) for horticulture. On the other hand, the 16 dynamic HRUs represent 50.6% of the total area and the 83% of rainfed agriculture, depicted mainly for extensive cereals 57.4%.

3. Results and discussion

3.1. LULC scenarios

The LULC scenarios derived from stakeholder mapping show the LU distribution, Fig. 5. The land dynamics include the land management of cropping patterns at HRU level. The rainfed agricultural land (yellow) is the major factor of change across the scenarios, followed by grassland (light green). The shift of rainfed to irrigated land in semiarid regions, as is the AdlB sub-basin case, involves significant differences in terms of water resources demand, even if area changes exceed de 1% of the sub-basin. The LU shift to irrigated crops is the result of the horticulture emerging structure in the area. This is the case of LBA scenario in which there is a slight increase in irrigated agriculture due to the expansion of irrigation schemes targeted by the River Basin Management Plan (RBMP). Urban and forest land covers were considered as constant LU in the three scenarios for this sub-basin. Fallow represented a larger area (7.94%) in baseline scenario as compared to LSH (0.24%), LBA (0.24%) and LSP (0.24%).

The interpretation of crop rotation maps from ITACyL forms up to 7.000 different rotational crop sequences considering individual

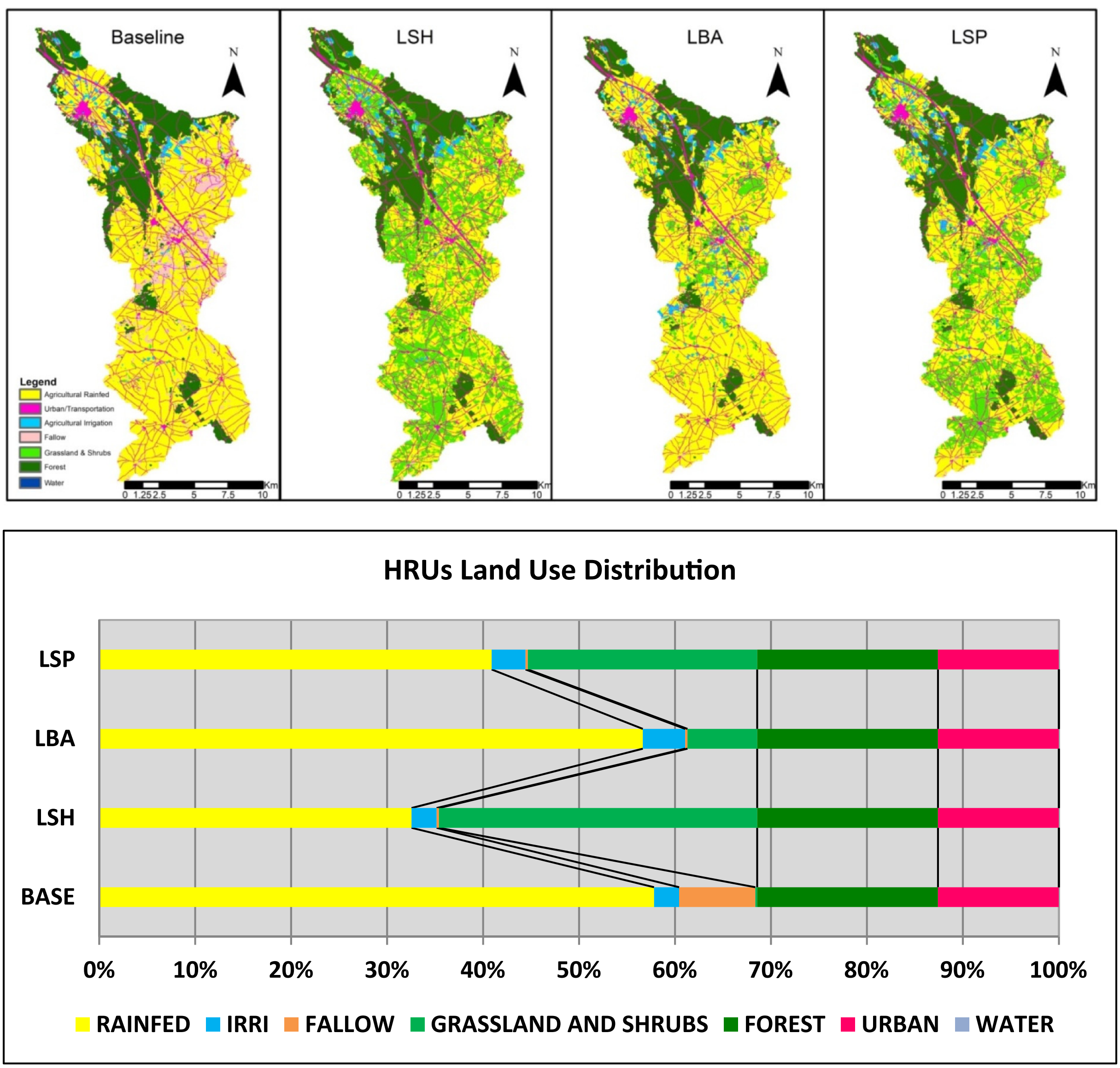

Fig. 5. Land use distribution for the scenarios land sharing (LSH), land balance (LBA) and land sparing (LSP) in comparison to Baseline scenario (BASE) for the subbasin studied ("*Arroyo de la Balisa*" AdlB).

parcels (series not shown). However, the sequence was reduced by identifying recurrent patterns in 5 years cycle basis. The crop rotation types (1-6) were defined based on remote sensing identification and grouping by mean spatio-temporal occurrence (see Fig. 6). Each pattern represented the most common cropland rotation system.

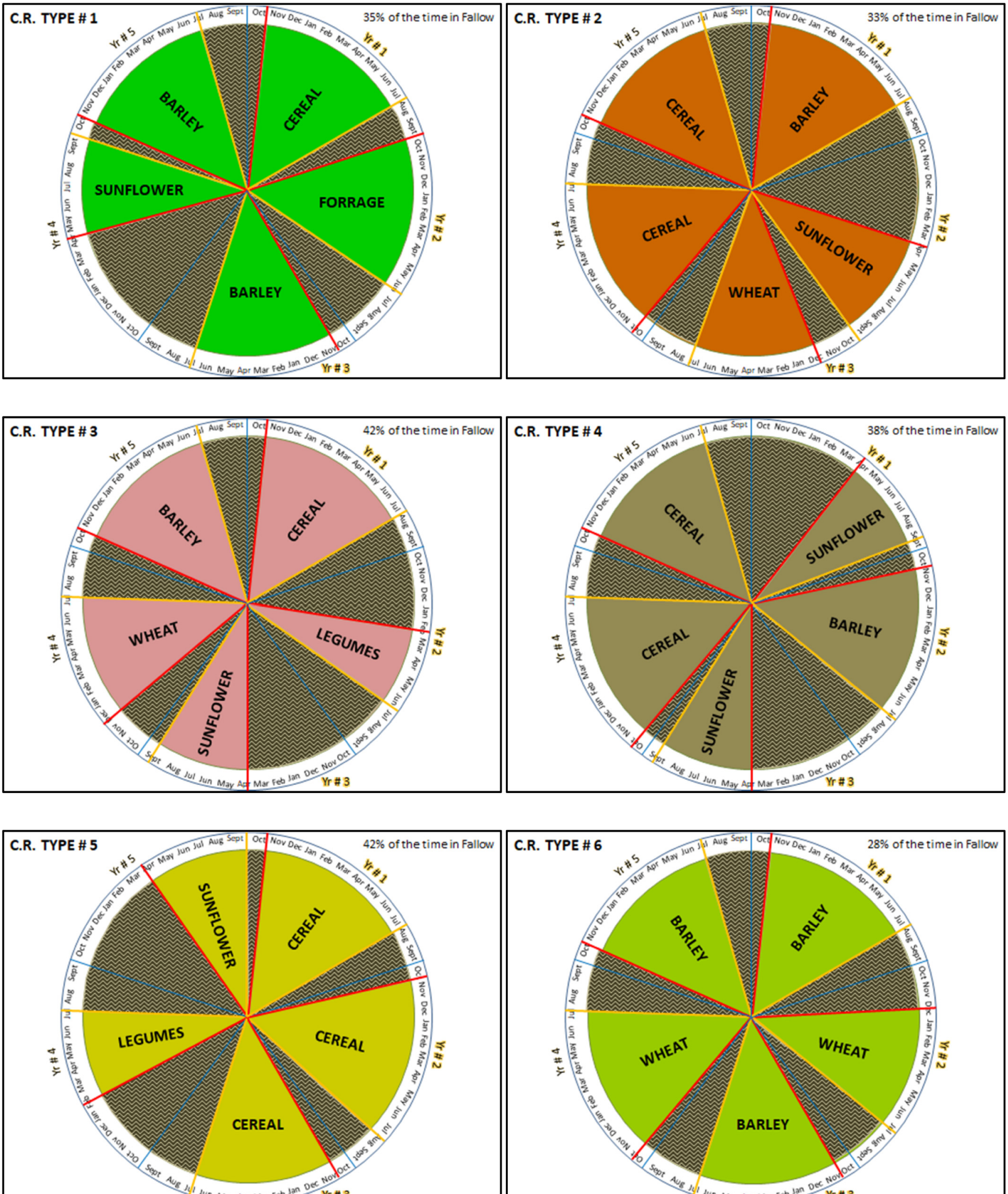

Fig. 6. The six cropland rotation patterns (C.R. TYPE #) identified from remote sensing in subbasin 443, "*Arroyo de la Balisa*". The sowing dates are in red lines, the harvest dates in yellow line and the hydrologic year bounds in blue lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

BASELINE

HRU	2004_2005*	2005_2006*	2006_2007*	2007_2008*	2008_2009*	2009_2010*	2010_2011*	2011_2012*	2012_2013*	2013_2014*
1	AGRC	PEAS	SUNF	WWHT	BARL	AGRC	PEAS	SUNF	WWHT	BARL
2	BARL	SUNF	WWHT	AGRC	AGRC	BARL	SUNF	WWHT	AGRC	AGRC
3	HAY	BARL	BARL	SUNF	BARL	HAY	BARL	BARL	SUNF	BARL
4	SUNF	BARL	SUNF	WWHT	BARL	SUNF	BARL	SUNF	WWHT	BARL
5	WWHT	BARL	AGRC	PEAS	BARL	WWHT	BARL	AGRC	PEAS	BARL
6	AGRC	PEAS	SUNF	WWHT	BARL	AGRC	PEAS	SUNF	WWHT	BARL
7	BARL	SUNF	WWHT	BARL	BARL	BARL	SUNF	WWHT	BARL	BARL
8	SUNF	BARL	WWHT	SUNF	BARL	SUNF	BARL	WWHT	SUNF	BARL
9	WWHT	BARL	BARL	WWHT	SUNF	WWHT	BARL	BARL	WWHT	SUNF
10	BARL	AGRC	SUNF	WWHT	PEAS	BARL	AGRC	SUNF	WWHT	PEAS
11	WWHT	BARL	BARL	SUNF	BARL	WWHT	BARL	BARL	SUNF	BARL
12	BARL	WWHT	BARL	BARL	WWHT	BARL	WWHT	BARL	BARL	WWHT
13	WWHT	WWHT	SUNF	WWHT	BARL	WWHT	WWHT	SUNF	WWHT	BARL
14	BARL	BARL	AGRC	PEAS	SUNF	BARL	BARL	AGRC	PEAS	SUNF
15	WWHT	AGRC	PEAS	WWHT	SUNF	WWHT	AGRC	PEAS	WWHT	SUNF
16	BARL	HAY	BARL	AGRC	SUNF	BARL	HAY	BARL	AGRC	SUNF

LAND SHARING (LSH)

HRU	2004_2005*	2005_2006*	2006_2007*	2007_2008*	2008_2009*	2009_2010*	2010_2011*	2011_2012*	2012_2013*	2013_2014*
1	BARL	SUNF	WWHT	AGRC	AGRC	BARL	SUNF	WWHT	AGRC	AGRC
2	WWHT	BARL	AGRC	PEAS	BARL	WWHT	BARL	AGRC	PEAS	BARL
3	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
4	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
5	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
6	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
7	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
8	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
9	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
10	AGRC	PEAS	SUNF	WWHT	BARL	AGRC	PEAS	SUNF	WWHT	BARL
11	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
12	BARL	WWHT	BARL	BARL	WWHT	BARL	WWHT	BARL	BARL	WWHT
13	WWHT	WWHT	SUNF	WWHT	BARL	WWHT	WWHT	SUNF	WWHT	BARL
14	BARL	BARL	AGRC	PEAS	SUNF	BARL	BARL	AGRC	PEAS	SUNF
15	WWHT	AGRC	PEAS	WWHT	SUNF	WWHT	AGRC	PEAS	WWHT	SUNF
16	BARL	HAY	BARL	AGRC	SUNF	BARL	HAY	BARL	AGRC	SUNF

LAND BALANCE (LBA)

HRU	2004_2005*	2005_2006*	2006_2007*	2007_2008*	2008_2009*	2009_2010*	2010_2011*	2011_2012*	2012_2013*	2013_2014*
1	BARL	SUNF	WWHT	AGRC	AGRC	BARL	SUNF	WWHT	AGRC	AGRC
2	HAY	BARL	BARL	SUNF	BARL	HAY	BARL	BARL	SUNF	BARL
3	WWHT	BARL	BARL	WWHT	SUNF	WWHT	BARL	BARL	WWHT	SUNF
4	BARL	SUNF	WWHT	BARL	BARL	BARL	SUNF	WWHT	BARL	BARL
5	WWHT	BARL	BARL	WWHT	SUNF	WWHT	BARL	BARL	WWHT	SUNF
6	BARL	SUNF	WWHT	BARL	BARL	BARL	SUNF	WWHT	BARL	BARL
7	HORT	HORT	HORT	HORT	HORT	HORT	HORT	HORT	HORT	HORT
8	BARL	SUNF	WWHT	BARL	BARL	BARL	SUNF	WWHT	BARL	BARL
9	WWHI	BARI	BARI	WWHI	BARI	WWHI	BARI	BARI	WWHI	BARI
10	SUNF	BARL	WWHT	SUNF	BARL	SUNF	BARL	WWHT	SUNF	BARL
11	SUNF	BARL	WWHT	SUNF	BARL	SUNF	BARL	WWHT	SUNF	BARL
12	BARL	WWHT	BARL	BARL	WWHT	BARL	WWHT	BARL	BARL	WWHT
13	WWHT	WWHT	SUNF	WWHT	BARL	WWHT	WWHT	SUNF	WWHT	BARL
14	BARL	BARL	AGRC	PEAS	SUNF	BARL	BARL	AGRC	PEAS	SUNF
15	WWHT	AGRC	PEAS	WWHT	SUNF	WWHT	AGRC	PEAS	WWHT	SUNF
16	BARL	HAY	BARL	AGRC	SUNF	BARL	HAY	BARL	AGRC	SUNF

LAND SPARING (LSP)

HRU	2004_2005*	2005_2006*	2006_2007*	2007_2008*	2008_2009*	2009_2010*	2010_2011*	2011_2012*	2012_2013*	2013_2014*
1	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
2	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
3	BARL	SUNF	WWHT	BARL	BARL	BARL	SUNF	WWHT	BARL	BARL
4	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
5	BARL	SUNF	WWHT	BARL	BARL	BARL	SUNF	WWHT	BARL	BARL
6	BARL	SUNF	WWHT	BARL	BARL	BARL	SUNF	WWHT	BARL	BARL
7	BARL	SUNF	WWHT	BARL	BARL	BARL	SUNF	WWHT	BARL	BARL
8	BARL	SUNF	WWHT	BARL	BARL	BARL	SUNF	WWHT	BARL	BARL
9	HORT	HORT	HORT	HORT	HORT	HORT	HORT	HORT	HORT	HORT
10	SUNF	BARL	WWHT	SUNF	BARL	SUNF	BARL	WWHT	SUNF	BARL
11	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE	RNGE
12	BARL	WWHT	BARL	BARL	WWHT	BARL	WWHT	BARL	BARL	WWHT
13	WWHT	WWHT	SUNF	WWHT	BARL	WWHT	WWHT	SUNF	WWHT	BARL
14	BARL	BARL	AGRC	PEAS	SUNF	BARL	BARL	AGRC	PEAS	SUNF
15	WWHT	AGRC	PEAS	WWHT	SUNF	WWHT	AGRC	PEAS	WWHT	SUNF
16	BARL	HAY	BARL	AGRC	SUNF	BARL	HAY	BARL	AGRC	SUNF

Fig. 7. Template for the main crop rotation patterns in Sub-basin 443, "*Arroyo de la Balisa*", for the baseline and the three scenarios.

The fallow practice in rainfed systems in central Spain is common in cereal-based crop rotation (Alonso, 1980; Moret et al., 2006). The fallow period occurred yearly or two yearly. This practice was considered in this study only as an intermediate practice during the yearly crop rotation scheme. Regularly, the fallow is also considered as a yearly or two-years practice in the rotational schemes. However, stakeholders favoured reducing the fallow period using other strategies to compensate for nutrient cycling and soil recovery. The yearly fallow suppression in management scheduling responds to three main reasons: i) low area representativeness for the total area, ii) the Duero's midlands responded significantly to a farmer decision (i.e. scheduling, soil fertility and water storage, market behaviour of rainfed products and machinery disposal) and iii) cereal under monocrop situation as extensive historical practice.

The crop rotation dynamics of the 16 HRUs represented the active and variable fractions across the scenario assessment. The crop sequences were assigned to preserve the actual pattern and consider the results of the workshop storylines. The resulting crop rotation sequence for the 16 HRUs of each LU scenario are shown in Fig. 7. The major changes were in the LSH scenario, where there are 8 HRU fixed with grassland use for all the simulation period. In LSP, monocrop sequences featured in six HRUs, including four grassland HRUs. There are HRUs for irrigation, three in the LBA scenario and one in LSP, in both cases assigned to horticulture. Once the grassland and the irrigated horticulture were included in the crop rotation, they remained present across the scenarios.

In the context of future land scenarios in the Mediterranean, agriculture is also facing most of the global changes, where desertification risk is a major concern with a significant part of the territories with a highly/very high susceptibility to landscape degradation. For example, Spain is accounting for 240,000 km^2 risked area (49% of the territory) and Portugal to 24,000 km^2 (28%) (Pravalie et al., 2017). Semiarid conditions and rainfall variability are common climate drivers for Spanish and Portuguese farmers, who are forced to convert the traditional rainfed

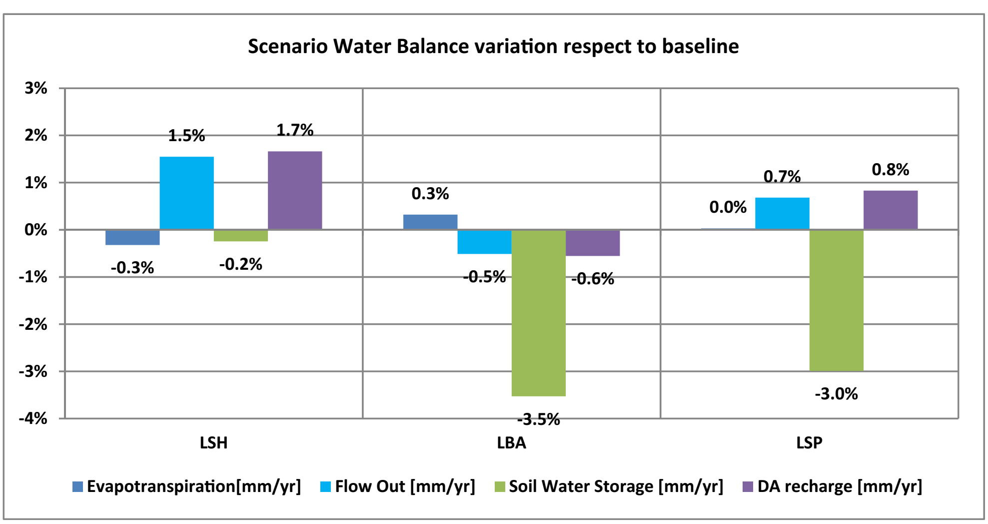

Fig. 8. Annual water balance components variations of the three land use scenarios (LBA: land balance, LSH; land sharing and LSP; land sparing) in comparison to baseline scenario. Calculation based on 10-years average period.

Fig. 9. Box plots of the main water balance components across the three LULC scenarios: Land sharing (LSH), Land Sparing (LSP) and Land Balance (LBA). Calculation based on 10-years average. The six graphs from the top to bottom correspond to: (a) ET – evapotranspiration, (b) FLOW_OUT – stream flow out of the sub-basin, (c) LATQ – lateral flow, (d) GWQ – groundwater recharge flow, (e) W_YIELD – total water yield, and (f) DA – deep aquifer recharge. The X axis represents the hydrological cycle in Spain that begins in October and ends in September of the following year and which also corresponds to the agricultural seasons.

agriculture to a more productive agro-system (Castro and Castro, 2019). Farmers are improving the water use efficiency (Ortega et al., 2005), introducing high-value crops varieties (García Morillo et al., 2015; Kropff et al., 2001) or managing multifunctional pastures (Teixeira et al., 2014). However, this situation intensifies the impacts (i.e., more production in less land, more water and inputs required), the abandonment of marginal land in extensive rainfed areas (García-Ruiz, 2010). All these actions cause a landscape effect in the reallocation of agriculture and a shift from traditional rainfed crops to intensive irrigated agriculture (Fornés et al., 2005; Pinilla, 2006). On the one hand, the evolution of the current socio-ecological systems trending towards the landscape greening-up and towards land degradation, each with enormous consequences for the environment (van Leeuwen et al., 2019) (van Leeuwen et al., 2019).

3.2. Water balance simulations

The variation of the main water balance components between the baseline and the different scenarios is shown in Fig. 8. However, the volume differences are smaller when annual values are compared. Nevertheless, in Mediterranean basins, interpreting monthly volumes variations can significantly affect water resources availability. Thus, the effect of LULC across scenarios is showed accentuated for intra-annual variability, and overall annual changes should be cautiously examined. The results of changed water balance components present a relative change to the baseline scenario, so are affected by the modelling uncertainty and need to be taken with some caution in management practice.

Although streamflow does not differ between scenarios, intra-annual variability of streamflow is associated with ET demand. The variation of the actual evapotranspiration (ET) across the catchment and for the different scenarios is the most relevant change, Fig. 9. This variation is directly related to the LULC distribution and crop management. The main hydrological effects are related to the out-going streamflow and the deep aquifer recharge during the spring-summer period. The ET during March-July presented a higher variability than the baseline, highlighting a lower ET in the LSH scenario during April and May.

In the case of LSH, a slight decrease of ET (-0.3%) is compensated for by an increase of flow out (1.5%) of the sub-basin and an annual deep aquifer recharge (1.7%) as can be observed in Fig. 8. However, the ET during June and July in LSH is higher than the other scenarios due to grassland coverage. Despite this, the streamflow out (median and Q3) is slightly higher and similar to the lateral flow because streamflow is composed of surface runoff, lateral flow and groundwater contribution. This result is partly explained by a decrease in the fallow land area (-7.7%) and increased pastures 33% in LSH, 23.7% in LSP and 7.1% in LBA concerning the baseline. The increase of ET in the scenarios concerning the baseline is crucial. The ET reduction in LSH turns into beneficial management for surface and groundwater bodies' protection by increasing its flows. Similar findings related to soil-vegetation dynamics in Mediterranean ephemeral small basins were described in Italy under climate change scenarios (Pumo et al., 2016).

However, the decrease in ET was not the only factor responsible for water bodies' increase in the LSH scenario. The soil was the determining factor for watershed regulation and cycle direction. A decrease of soil moisture in the sub-basin constituted an essential source for water regulation (-3.5% in LBA and – 3.0% in LSP) due to soil characteristics such as hydraulic conductivity and soil depth (Fig. 8). Despite this, the soil moisture balance was favoured in fallow land. The water retention in sandy soils was very low. Therefore, the aquifer recharge increased (+1.7% in LSH), and the lateral flow contributed to a streamflow increase of 1.5% of the watershed flow.

In contrast, the LBA scenario was closer to the baseline, highlighting that this scenario worsened deep aquifer recharge, especially during the summer flows. The ET in LBA was higher than baseline in March and April and very close to the baseline during the late spring and summer. This result suggests that the LBA strategy was worse than the baseline for the water bodies' regulation (both surface and groundwater) in late spring and during the summer, which is the critical period of hydric stress.

A slight increase of the ET in LSP compared to baseline resulted in a 3.0% decrease in soil water storage, while an increase of 0.3% of ET in LBA resulted in -3.5% of soil water storage (Fig. 8). However, while in LSP, the deep aquifer recharge was 0.8%, in LBA was −0.6% on average. The relation between ET and land cover affected the water-bodies flows. A reduction of fallow area and an increase of pastures area, compared with the baseline, showed increased water quantity for the watershed in waterbodies protection. Though water quantity regulation is crucial in semiarid watersheds, water quality and sediments assessment are needed to optimise the scenarios (Molina-Navarro et al., 2014).

As yearly practised in Mediterranean basins, the fallow is very important as part of rainfed cropping systems. It reduces evapotranspiration as there is a reduction in plant transpiration. At the same time, it increases water storage throughout the soil profile and encourages nutrient mineralisation (Gómez De Barreda Ferraz, 2011; Lacasta, 1995). Similar findings were detected in semiarid conditions in central Chaco Paraguay (Cáceres and Ratzlaff, 2013), where ET reduction also depends on the soils types and tillage practices. Other research also emphasises the high variability of the monthly soil moisture compared to single year water balances, e.g., in the Duero watersheds (Vicente Gonzalez et al., 2016). In addition, the relationship of soil moisture with ET and the implications of different LU's on water regulation requires the ET from rainfed crops and ET from natural covers such as pastures are treated separately.

The unseeded fallow land in central Spain is subjected to intensive tillage. Usually, there are four tillage operations: three ploughings (after harvest, fall and winter) and rotary hoe for weeds suppression (summer). These operations are associated with erosion processes (Boellstorff and Benito, 2005; De Alba et al., 1999) and water quality problems (Alba et al., 2011; Nadal-Romero et al., 2019), creating a risk at the semiarid ecosystems in central Spain. For this reason, we suggest that further research should focus on the yearly fallow practice must be reduced and included as a strategy for rainfed crop rotation schemes in Mediterranean ephemeral streams.

4. Conclusions

- Participatory scenario mapping was a helpful approach to integrate stakeholder knowledge into the development of quantitative LULC, which were a fundamental input for setting up the scenario databases in SWAT.
- The land sharing (LSH) scenario represented the most useful LU strategy among the three scenarios to protect surface and groundwater bodies.
- The land sharing (LSH) scenario represents among the three scenarios the most likely LU strategy to favour stream flow configuration and deep aquifer recharge in this semiarid sub-basin.
- The fallow should be included as a crucial yearly practice in rainfed crop rotation schemes in Mediterranean basins. Since this choice suppose an essential strategy for water balance regulation in this sub-basin. However, despite fallow suppression also fulfils strategic measures for water quality regulation, a balance about yearly fallow land is needed. The assessment, through modelling, of this effect should be coupled to water quantity and quality to analyse the overall effect on the basin water resources.
- In Mediterranean rural basins, the crop rotations are very sensitive to water resources variability. The rotations and their location in basins must be rethought to achieve the environmental goals.

CRediT authorship contribution statement

David Rivas-Tabares: Data curation, Visualization, Writing- Original draft preparation, Methodology, Validation, Software. **Ana M. Tarquis**: Supervision, Methodology, Investigation, Funding, Writing- Reviewing and Editing. **Ángel De Miguel**: Conceptualization, Methodology. **Anne**

Gobin: Writing- Reviewing and Editing. **Bárbara Willaarts:** Conceptualization, Methodology, Investigation Writing- Reviewing and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.149906.

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