COASTAL
Collaborative Land-Sea
Integration Platform

Deliverable D16 - Application of generic feedback structures to support business and policy analysis

Final Version

WP 4, T 4.5
Lead beneficiary: (VITO)

Authors: Peter Viaene and Jean-Luc de Kok (VITO), Erika Palmer and Anne Gaspers (SINTEF)

Contributing Authors:

Aris Karageorgis, Yiannis Panagopoulos and Erasmia Kastanidi (HCMR), Georgia Destouni, Zahra Kalantari, Guillaume Vigouroux, and Giorgos Maneas (SU), Françoise Vernier, Jean-Marie Lescot and Benoit Othoniel (INRAE), Luminita Lazar (NIMRD), Steliana Rodino and Ruxandra Pop (ICEADR), Joris de Vente, Raquel Lujan and Victor Castillo (CSIC)

Approved by WP Coordinator: Peter Viaene (VITO)
Date of approval: 11 July, 2022
Approved by Project Coordinator: Jean Luc De Kok, VITO
Date of approval: 13 July 2022
Planned date of deliverable: 30.06.2022
Actual submission date: 13 July 2022

This project has received funding from the European Union's

H2020-RUR-02-2017

Project number: 773782

Project duration: 1 May 2018 – 31 October 2022

Project coordinator: Jean-Luc De Kok, VITO

Project web site: https://h2020-coastal.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782

Dissemination level		
PU	Public	X
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified information as referred to in Commission Decision 2001/844/EC)	

Deliverable type		
R	Document, report	X
DEM	Demonstrator, pilot, prototype	
DEC	Web sites, patent fillings, videos, etc.	
OTHER	Software, technical diagram, etc.	

History			
Version	Date	Reason	Revised by
1.0	14/4/2022	Initial version- structure	Peter Viaene
1.2	24/05/2022	1st Draft	Erika Palmer / Anne Gaspers
1.3	11/07/2022	Final version	Peter Viaene
2.0	13/07/22	Final cross check	Jean-Luc De Kok

Partnership:

This document was produced under the terms and conditions of Grant Agreement No. 773782 for the European Commission. It does not necessary reflect the view of the European Union and in no way anticipates the Commission's future policy in this area

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782

Executive summary

The responsibility for developing, validating and applying System Dynamics (SD) models for land-sea interactions lies with Work Package 4 (Systems Modelling). The SD models will be used to formulate and support strategic business and policy analyses aimed at improving coastal-rural synergies. For this, separate SD models of the coastal-rural interactions were developed for each case study, starting from the qualitative understanding of these interactions developed in WP1. The qualitative analysis in WP1 resulted in a set of Mind Maps and Causal Loop Diagrams (CLD) describing the different interactions identified for each of the MALs. Instead of directly converting the overall CLD resulting from WP1 into a SD model per MAL, it was decided to divide the overall problem into several smaller problems and translate these into individual SD models.

In this deliverable we describe on a MAL-by-MAL basis the application of the SD models that were developed. First, the major issues that were identified for each of the MALs and on which the SD modelling is based are presented. Next the final SD model structure and the process(es) modelled are described. To conclude, the practical application and policy relevancy of the models is addressed. This deliverable ends with overall reflections on SD modelling in the project and the policy context – bridging the quantitative modelling to the policy outcomes. The latter will be presented in a separate deliverable for WP3. All final stock-flow models are made available following the FAIR guidelines through the Zenodo Open Data Platform (https://zenodo.org/communities/773782-coastal/).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782

Table of content

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 773782

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 773782

List of Tables

This project has received funding from the European Union’s Horizon 2020
research and innovation programme under grant agreement N° 773782

List of Figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 773782

Abbreviations and acronyms

BSAP	Baltic Sea Action Plan
CAP	Common Agricultural Policy
CLD	Causal Loop Diagram
LSI	Land-Sea Interaction
MAL	Multi-Actor Lab
REA	Research Executive Agency
SD	System Dynamics
SF	Stock-Flow
WFD	Water Framework Directive

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 773782

1. Introduction

1.1. Stock-flow modelling

The COASTAL sector workshops, organised in the second half of 2018 for the MALs, were aimed at developing mind maps for specific sectors (agricultural, environment, water management, fisheries, …). Processing and polishing of these mind maps resulted in more refined conceptual models, which were used to formulate graphical Causal Loop Diagrams (CLDs) showing the relevant feedback mechanisms explaining the problem qualitatively. Capturing the feedback mechanisms in terms of quantitative stocks and flows affecting the increase or decrease of the stocks is a core activity in System Dynamics modelling (Sterman, 2000). Converting the CLDs into stock-flow models allows quantifying policy and business alternatives under different scenarios in an evidence-based manner. This requires an effort in terms of defining the stock-flow architecture, collecting quantitative data for parameter settings, formulating equations, model calibration and model validation. Nevertheless, there are several advantages to quantitative modelling, the main ones being: (1) a model provides an objective structure allowing evidence-based analyses, (2) the stock-flow models can handle the complexity of system transition, (3) pinpointing of tipping points and significant control levers, (4) a framework which can be used for multiple scenarios with adaptable parameter settings and (5) sensitivity analyses for policy alternatives can be carried out. Well-designed models and model structures can be polished, documented and exchanged between collaborative research teams and managed in a generic library of reusable model components (Task 4.4).

A common mistake made by modellers who are not or less experienced with stock-flow or System Dynamics (SD) modelling is to translate their CLDs one-on-one into a stock-flow model and add as much detail as possible and considered relevant from a single theme perspective (water resources management, agriculture, tourism development, …). This quickly results in model clutter and models which are difficult to design, maintain and use. Instead, the focus should be on the feedback structures, and in particular the cross-thematic interactions. One of the misunderstandings is also that stock-flow models are always more complex than the CLDs obtained in the preceding analysis phase (Sterman, 2000). On the contrary, in some cases, stock-flow structures can even have a more condensed graphical appearance due to the use of mathematical equations and non-linear functions. From the start work task 4.2 – SD modelling of coastal-rural interactions - faced three challenges:

- to ensure proper alignment of the quantitative stock-flow modelling with the qualitative analyses resulting from the stakeholder engagements in the first project phase (problems, solutions and barriers, and land-sea interactions);
- to tune the design of the models to the purpose of analysing coastal-rural interactions, taking into account the availability of data and the role of system uncertainties (addressed with scenarios developed under Task 5.3);
- to assist the Multi-Actor Lab teams with their modelling in a systematic way, ensuring streamlining of results;

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782

- Ensuring models are evidence-based, using available data and validated.

Differences in scope, modelling expertise and modelling preferences, and data availability are factors which can be expected to affect the design, reusability and quality of models, as well as the efficiency of the modelling process. The philosophy and main principles of SD modelling were outlined in the Problem Scope (deliverable D12) and a number of tutorial sessions, starting with the kick-off meeting in Methoni, Greece in May 2019. Understanding and addressing problems by identifying the underlying feedback mechanisms was explained in a stepwise manner, using examples for tourism development and groundwater use. These examples turned out to be useful for communicating the general principles of SD modelling, but more was needed to get all MAL teams started with modelling their own systems as many of the MAL modelling teams had little or no experience using and developing SD models.
Several measures were taken to maximize the efficiency and harmonization of the modelling:

- Instead of modelling the complete system in a top-down manner, covering all interactions indicated in the Causal Loop Diagrams as presented in deliverable D4, the MALs were encouraged to identify the priorities for their modelling and first develop sub models, which only were to be integrated once these were running;
- The MAL teams were assisted through weekly exchanges with the WP coordinator to discuss the progress of the modelling, problems and develop solutions. Initially, these meetings were organised with all teams. Later, follow up was organised on an individual basis for those teams that needed support ;
- Additional tutorials and guidelines were distributed to direct the modelling at a strategic level;
- Technical support for model documentation and online exchange of models through the project website and share point were provided. The exchange of models was also facilitated by adopting VenSim® as a single, common modelling platform;
- Modelling workshops were organised, during the General Assembly meeting in Methoni and back to back with the first Review meeting in Brussels, as these were occasions where everyone was already present.
- A structured template for deliverables including examples was provided.

The general modelling strategy communicated to the partners was based on three principles:

1. identify the key stock variables based on the causal loop diagrams;
2. follow a step-by-step design process with gradual increase of complexity of the models;
3. focus on the quantification by measurable variables, use of response functions and correct units of measurement and identify and account for system limiting factors.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 773782

1.2. How does the stock-flow modelling relate to the rest of the project?

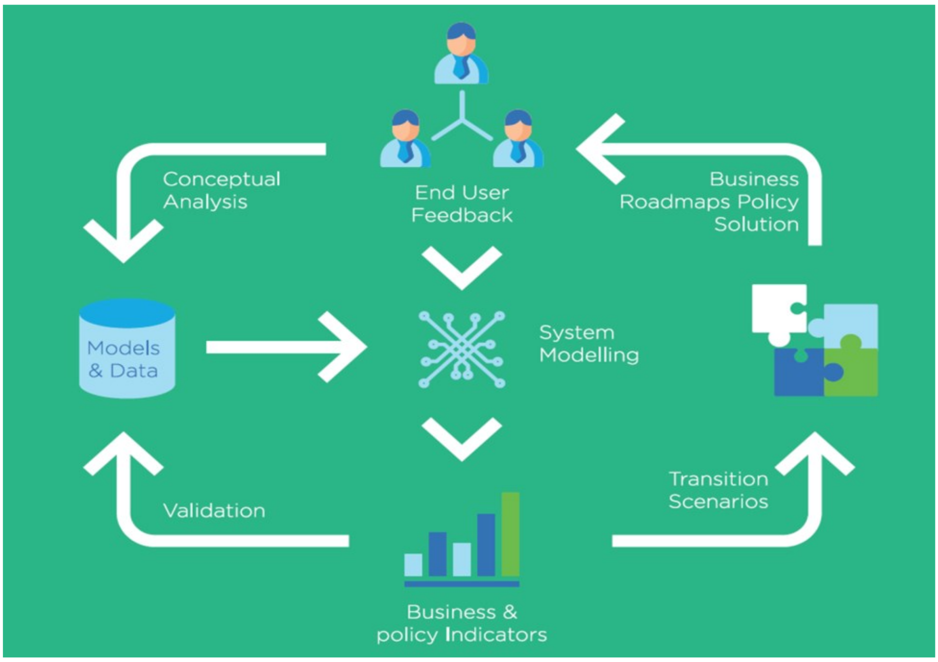


Figure 1: Pivotal role of the systems modelling in the COASTAL project.

In COASTAL, the quantitative stock-flow modelling has a pivotal role and both contributes and depends on other work packages (Figure 1). WP1 (multi-actor analysis) and WP2 (Knowledge Transition) pave the way for the stock-flow modelling by identifying and prioritizing the land-sea interactions, determining the system feedback structure and developing expert and local knowledge as well as data needed for the modelling. In addition, WP5 will interact with WP4 to develop consistent scenarios for driving the models and addressing the social-economic uncertainties in the models. Both WP3 (business & policy analysis) and WP5 (policy robustness) depend on the availability and quality of the models for developing evidence-based business road maps and policy actions. The stock-flow models will be used to formulate and support strategic business and policy analyses aimed at improving coastal-rural synergies. To achieve this, separate stock-flow models of the coastal-rural interactions were developed for each case study, starting from the qualitative analysis in WP1 which resulted in a set of Mind Maps and Causal Loop Diagrams (CLD) describing the different interactions identified for each of the MAL.

1.3. Research versus policy modelling

SD models are excellent tools for integrating thematic models and expertise (Figure 2). A common misunderstanding is to confuse the type of modelling for detailed thematic models ('silo models') and the detail in data these require with that of the SD model layer that integrates the 'silo models'. Ideally the collection of data should be driven by the model design rather than the other way around as deriving model structure from data will often result in a loss of focus in model purpose. As COASTAL demonstrates modelling and data development can take place in parallel, and an iterative approach is sometimes preferable. This

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 773782

could start from historic data for an observed problem, which is to be explained from the system feedback structure.

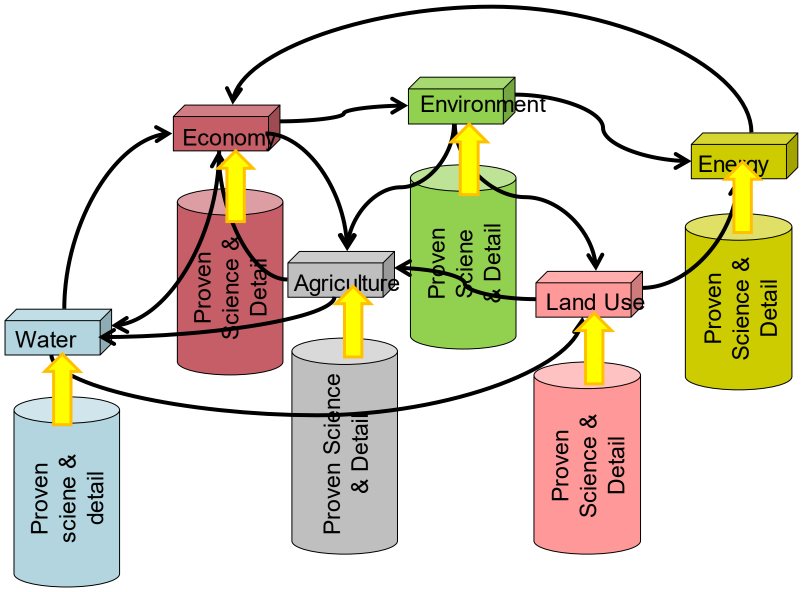


Figure 2: Thematic integration using a system dynamics framework (De Kok et al., 2015). The detailed 'silo' models are represented by the bottom, coloured columns. The SD model layer links the simplified representations of each of the silo models (smaller boxes).

Some major differences in design, purpose and use of thematic and policy models are presented in Table 1. It is important for model developers, in particular experienced modelers, to be aware of these differences when designing SD models to avoid the common pitfall of directly translating their silo models into stock-flow models.

Table 1: Differences between thematic 'silo' modelling and SD modelling.

Thematic Models (cylinders)	**Policy Model (System Dynamics)**
time horizon, temporal and spatial resolution are *process* centred	time horizon, temporal and spatial resolution are *policy problem* centred
accurate representation of processes	*adequate* representation of processes
model propels data collection	*data constrain* model development
in depth and sectorial	*sketchy but integral*
as complicated as necessary	*as simple as possible*
scientifically *innovative*	scientifically *proven*
raises more *questions* than answers	build to provide *'definite' answers*
interesting and worthwhile *in their own right*	interesting and worthwhile only *through their output*
numbers validatable	*outcomes* validatable
response time, interactive-use *not critical*	response time, interactive-use *critical*
transparency & user-friendliness not an issue	transparency and user-friendliness are critical
the developer is the user	end-user involvement during development is critical

1.4. Purpose and structure of this deliverable

The main goal of this deliverable is to present the final SD models developed by the MALs highlights and the policy relevance of these models and the value of stock-flow modelling for policy analysis.

In the next chapters of this deliverable, we describe on a MAL-by-MAL basis the model scope identified for the MAL and details on the architecture, quantitative framework and data and functionalities of the final SD model(s) for each case study. Where previous deliverables stopped at model development, this is complemented in this deliverable with a reflection on possible improvements and limitations, on the challenges encountered and on the use of the models in a policy context bridging the quantitative modelling to the policy outcomes. The policy outcomes themselves will be presented in a separate deliverable for WP3. At the end of the MAL specific discussion, a general consideration of the use of SD modelling for policy support and a synthesis based on the MAL inputs is provided. As the Knowledge Exchange Platform is an important outcome of the project the contribution of the models to the Knowledge Exchange Platform is also discussed. All final stock-flow models are made available following the FAIR guidelines through the Zenodo Open Data Platform (https://zenodo.org/communities/773782-coastal/).

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 773782

2. Application of SD models for the MALs

2.1. Multi-Actor Lab 1 - Belgian Coastal Zone (Belgium)

2.1.1. Problem scope of the land-sea system

The Belgian coast (67 km length) and hinterland face environmental and economic stresses from intensive multifunctional use of the limited space that is available. Land- and sea-based activities such as agriculture, fisheries, agro-food industry, transport, energy production and recreation are closely interwoven and compete for space (Figure 3).

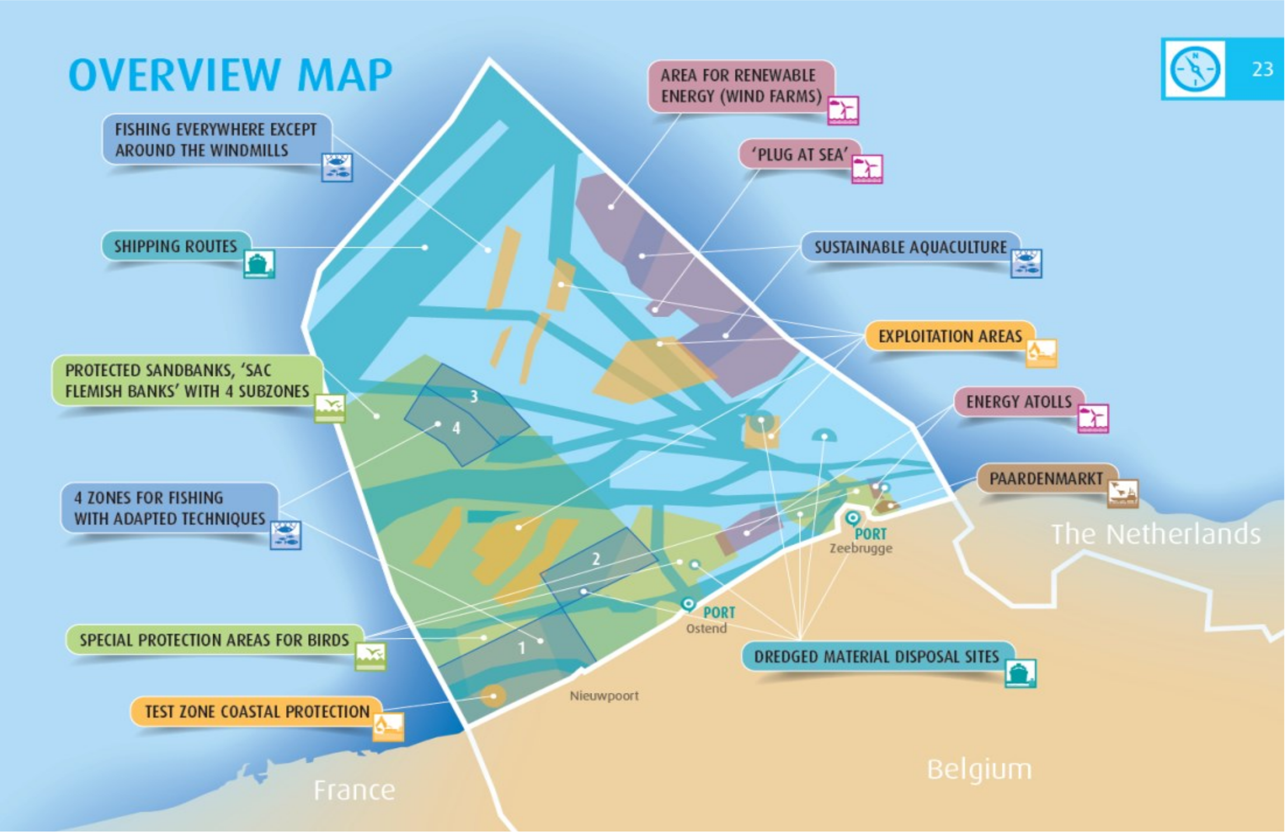


Figure 3 Overview Map for Marine Spatial Planning in the Belgian Coastal Zone (with permission Belgian Federal Public Service Health, Food Chain Service and Environment, 2015)

New development opportunities for this densely populated region are created by blue growth, and especially on- and offshore energy production which create opportunities for new jobs and strategic specialization of port activities. This includes innovative production methods using wave and tidal energy. Belgium is one of the leading countries in know-how related to offshore energy production and the first country to put in practice multi-purpose use of wind farms where e.g. these are combined with shellfish aquaculture. Meanwhile, the quality of freshwater resources is under pressure, and land-based emissions of nutrients still exceed the EU-WFD target levels and contribute to coastal eutrophication. The quantities of fresh water are under pressure during extended periods of drought, as a result of multiple demands from industry, tourism,

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782

population and agriculture. A major stressor is the increasing salinisation of inland waters, related to human waterworks, water management, and sea level rise. A main challenge for this case study is the fragmentation of policy and knowledge for coastal and rural development. A common administrative framework for coastal-rural integration is lacking and policy responsibilities are fragmented at the regional and national level.

2.1.2. Description of stock-flow models

After a number of adjustments to align with stake holder expectations, the modelling for the Belgian MAL focused on two stock-flows models: a model for sustainable climate adaptation and land management in the Oudlandpolder and a model for the logistic and economic impacts of decommissioning offshore wind parks in the Belgian North Sea. The two models differ in problem scope and were designed as strategic policy tools with a long-time horizon of decades to address the role of climate adaptation and energy transition. Referring to model structures shown in Figure 4 and Figure 5 (Oudland polder model) and **Error! Reference source not found.** (decommissioning model), we conclude both sub models provide support for systemic analysis:

1. For the **Oudland polder model**, the stock-flow model structure links land use planning with water management and gentrification in agriculture. The complexity of the model is in the equations and data rather than the feedback structure (Figure 4).
2. For the **port and energy model,** focusing on the decommissioning of offshore wind turbines, the systemic analysis covers the logistics, economic and energy aspects of offshore wind farming ().

For the Outland Polder model separate areas were introduced for agriculture and nature as requested by stakeholders to be able to model the effect on the water balance of managing separate compartments for the land occupied by agriculture and by nature. The water component of the SD model furthermore allows investigating the effect of changes in the different water sources and sinks including natural ones such as precipitation and evapotranspiration which will change with climate change but also water reuse from waste water treatment plants or rainwater collected from paved areas and the buffering of water in creek ridges which are affected by population dynamics and land and water management. A somewhat different topic covered by the SD model is the gentrification of farms in the polder region. While this is, as it is modelled now, mostly an autonomous process in the model, some feedback was introduced to account for effect of land use changes on gentrification. The gentrification model is also affected by the water management by considering the effect of water management on suitability for agriculture / nature. Land-sea interactions are included through the impact of sea level rise on water discharge for the polder. This is not an immediate concern for this region, but the problem was raised several times during the sector workshops and implies that the installation of pumps to remove water will be necessary in the future.

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement N° 773782

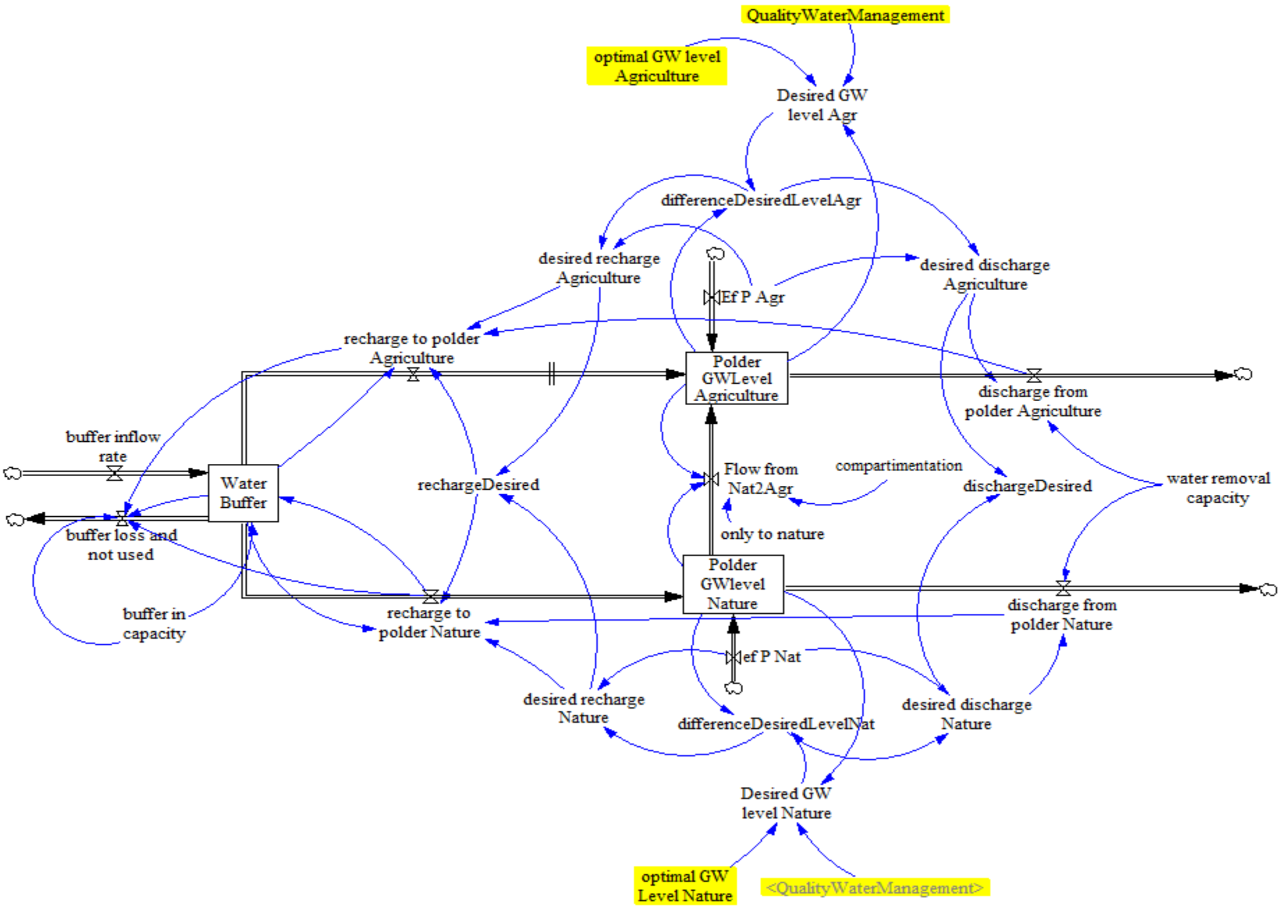


Figure 4: SD model for Oudland polder considering a separate water management regime in the agricultural and natural areas of the polder and allowing from considering separate compartments for each of these. The yellow variables are the inputs to the model.

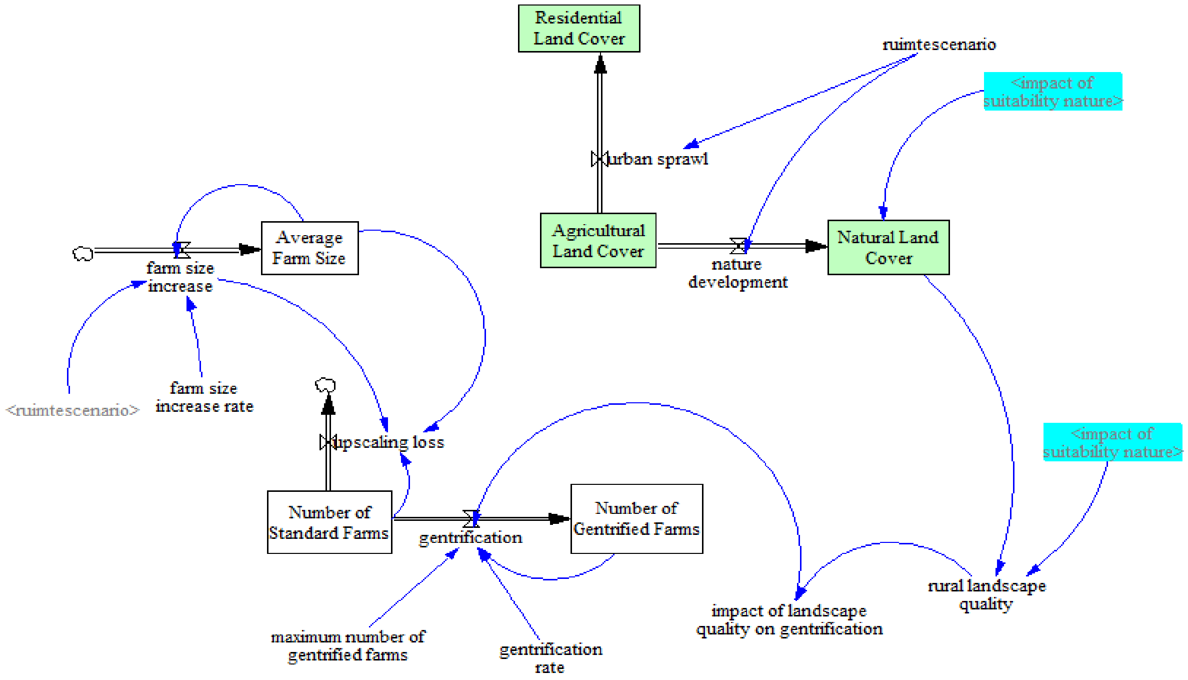


Figure 5: SD model for gentrification. The variables with a green background are based on another model (Ruimtemodel Vlaanderen). The variables with a blue background are interactions with the water management.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782

For the **port and energy model,** focusing on the decommissioning of offshore wind turbines, the systemic analysis covers the logistics, economic and energy aspects of offshore wind farming. With the decision to focus the model on the **decommissioning rate** and more specifically on the long-term pattern of the yearly number of decommissioned turbine, it was necessary to reconsider the definition of stock and flow variables and use the age-cohort system and age-based stocks (Figure 6) to build up the model.

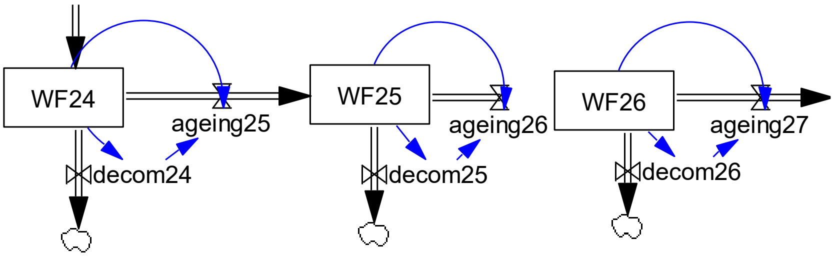


Figure 6: Age-cohort mechanism used for the wind turbined (graphical representation in VenSim).

At a general level, this is not a complex model both in terms of the feedback structure and equations used. Some feedback is present in the age-cohort chains. In line with the reality of marine spatial planning in the Belgian coastal zone, the model is strongly exogenously driven by planning scenarios for installation of the turbines and technological factors, such as the turbine capacity and maintenance costs. Intrinsically, the final model is a graphically designed accounting model. The holistic value of the model could be increased by including the impacts of systemic limitations, for example a lack of skilled labour or port space could limit the capacity for decommissioning the wind turbines. Some tests were run to examine the potential usefulness, but this was considered to be of academic and educational value rather than practical value for the priorities indicated by the actor partners. Therefore, the priority is given to improving the data used by the model and discussing the usefulness of the model simulations for long-term planning with selected stakeholders. This will be done in conjunction with the EU-funded project DecomTools[1], which focuses more on the engineering and technological aspects, and short-term planning of decommissioning. In the future, the model could be elaborated in terms of material reuse and the impacts/demands on port infrastructure.

2.1.3. Application 1: A systemic planning tool for land use and water management in the polder

2.1.3.1. Application rationale: Oudland polder

The Oudland polder is low lying polder area, mainly used for agriculture and located between the intensively used coastal zone, the canal Bruges-Ostend and the Boudewijn canal. A new Framework Contract was signed in April 2018 to address the challenges of climate robust water management for the polder. The practical implementation of this Framework Contract will be organized through a land management project,

---

[1] https://northsearegion.eu/decomtools/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773782

integrating water and land use management, which is coordinated by the Flemish Land Agency, a full COASTAL partner.

2.1.3.2. Results and discussion: Oudlandpolder

In the context of COASTAL a need was detected to develop a systemic planning tool, complementary to the existing hydrological model which is currently being updated and which is an operational tool intended to support daily water management decisions. The SD model is complementary in the sense that the time frame is different i.e. long term instead of short term and considers the interaction with other, non-hydrological systems. The model for the Oudlandpolder was designed to examine the impacts of water management interventions aimed at ensuring target water levels for agriculture and nature in combination with different scenarios for climate change, land use cover and agricultural crop schemes. To reflect the measures adequately, more detail was added than necessary and the model gradually developed into a lesser compromise between a hydrological process model and a systemic planning tool. Furthermore, the model does not yet include exchanges with the groundwater reserves. Due to the missing exchange which affects the water dynamics, the model is not considered to be ready for supporting the management of the Oudlandpolder without additional improvements, which is beyond the remaining resources. A recurring problem seems that it is difficult to convey to authorities the usefulness of a model which does not provide the detail and precision of the operational water balance models that they are familiar with. Nevertheless, the scenarios used by the model are considered very useful for visualizing impacts of climate change on the agricultural water demand under different crop schemes. Alignment with the Framework Contract is also very promising in this respect. A general observation, however, is that operational management requires tools and expertise which differs from the systemic policy models developed in COASTAL. The partners are now examining exploitation routes with target groups that could benefit from strategic planning tools with a systemic architecture, of which the added value is clear to all parties involved in the design of the Oudland polder model. The model can serve as a starting point for further development.

2.1.4. Application 2: A scenario tool for decommissioning windmills

2.1.4.1. Application rationale: Decommissioning wind parks

The model addresses the long-term impacts of decommissioning wind parks in the Belgian North Sea. Offshore wind farming started in 2008 and Belgium was one of the first EU countries with a Marine Spatial Plan to regulate the licensing of offshore area to new wind parks. The current capacity of the wind park covers around 10 % of the inland electricity demand. This contribution to achieving the EU climate goals is planned to increase considerable with the rapid development in terms of technology, expertise and infrastructure. Notwithstanding the exchanges between administrations, industry, academia and the public, for example in the Belgian Offshore Platform and Flemish Blue Cluster, debate is still strongly focused on the engineering challenges and financial models. The lifetime of wind turbines is currently around 20 -25 years and the first wind parks will soon be decommissioned, a huge operation involving technical, economic and environmental aspects. The port of Ostend is a central hub for wind energy deployment, maintenance and decommissioning. It will face logistic challenges when peaks occur in the number of decommissioned wind turbines. In addition, energy production should be ensured by timely replacement of the turbines.

2.1.4.2. Results and discussion: Decommissioning wind parks

Where originally, the model focused on offshore H2 production and energy storage, based on feedback of the local partners the decommissioning of wind parks was considered more relevant and the model was adjusted accordingly. The current model has been designed as a scenario tool covering the installation, removal, maintenance and power production of the turbines, with wind parks being (de)commissioned at irregular intervals. Scenarios can be defined and adjusted in a spreadsheet and are processed by the model into key indicators, the main one being the ‘decommissioning rate’, which is the number of turbines being decommissioned in a specific year.

The main added value of this tool is that it covers a science-policy niche and can help turn the debate more to the long-term logistic impacts of offshore renewable energy in an intuitive manner. Currently, such strategic planning tools do not exist and are complementary to expertise developed in technology driven projects such as DecomTools[3]. The exploitation route will examine opportunities for interacting with different platforms and projects to showcase the potential of strategic planning tools and collect data and expertise to improve the tool, increase its usefulness, and pave the way for applications in other EU regions.

2.2. Multi-Actor Lab 2 - South-West Messinia (Greece)

2.2.1. Problem scope of the land-sea system

South West Messinia (SW Messinia) is a representative example of an interlinked coastal-inland area in the Eastern Mediterranean region well known for its unique beauty and long history (Figure 7).

Figure 7: A view of the SW Messinia case study from Palaiokastro (check view point in Figure 8).

It is a rural area with small towns and villages (Figure 7). The landscape is mainly dominated by olive-trees, which were planted during the 1970s replacing other types of crops (Maneas et al., 2019). Part of the case study is designated as an Integrated Tourist Development Area (ITDA), which is one of the biggest tourist investments in Greece, and a major driver for the economy for the area. At the core of the case study lies a coastal wetland, which is part of a wider Natura 2000 site that includes a variety of Mediterranean habitats and cultural sites (Birds directive 2009/147/EC; Habitats Directive 92/43/EEC).

Tourism is expanding and goes hand in hand with infrastructure development (hotels, roads and airports), the creation of new job opportunities and can provide opportunities for diversified livelihoods but also increase the pressures on agriculture, water resources and the environment (Tiller et al., 2021; Maneas et al., 2019; Klein et al., 2015). The area produces olive-oil of high standards, but the current conditions (land fragmentation, willingness to cooperate) add limitations to the sustainability and growth of the sector (Tiller et al., 2021). In addition, the production of olives is mainly based on conventional farming practices (e.g., tillage, use of pesticides, herbicides and synthetic fertilizers), which result in higher run-off from agriculture and subsequently environmental degradation of coastal and marine areas (Tiller et al., 2021; Berg et al., 2018). At the same time, the wetland is in a bad environmental state, and unless actions are taken towards the restoration of hydrological conditions and the enhancement of its ecosystem services, it is expected that it may soon collapse with implications to fishing and tourism.

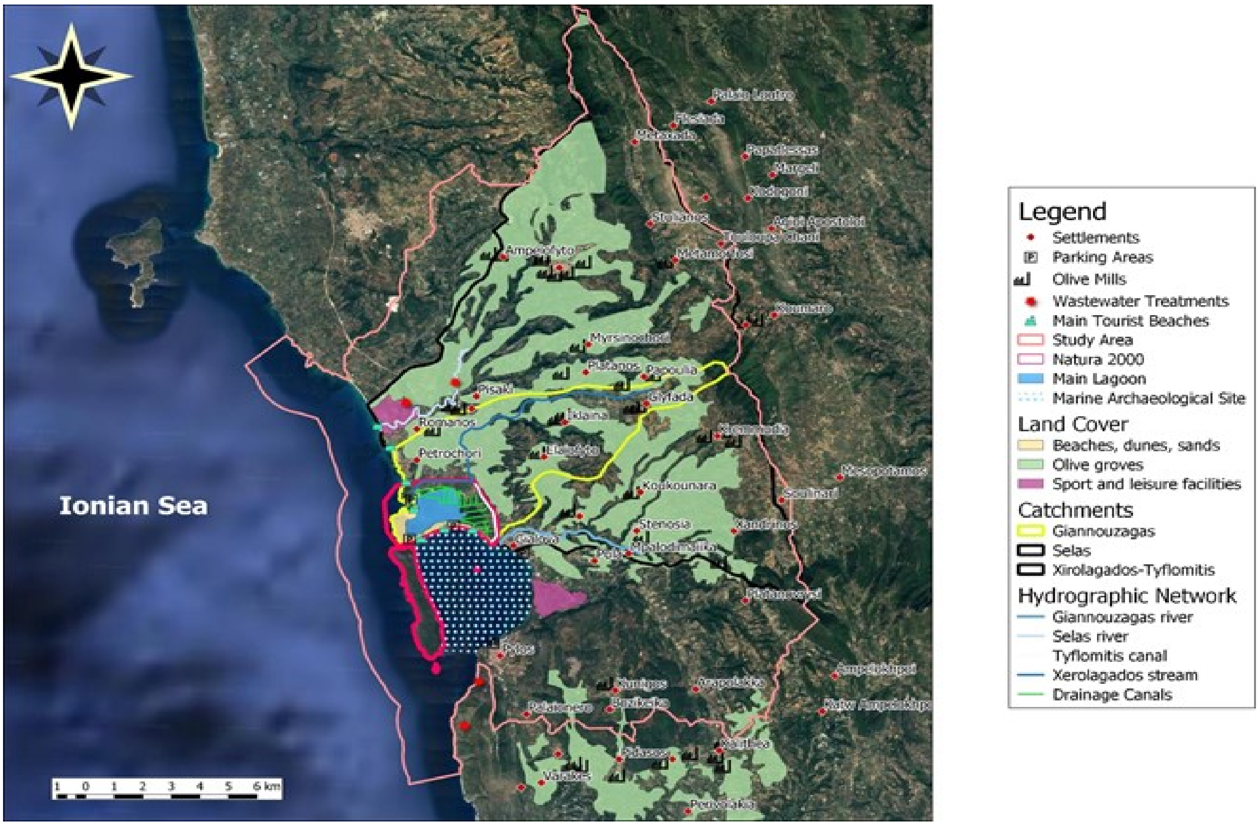


Figure 8: Land uses and pressures in the SW Messinia (Padazis, 2020).

2.2.2. Description of stock-flow models

Two operational models have been created based on the three initial pilot sub models (see below).

The Water – Wetland sub model focuses on the restoration of the local wetland which is of high ecological and cultural importance and has an economic value due to fishery and potential development of eco-touristic activities. The land-sea interactions which are examined are:

- Groundwater availability for the restoration of salinity in the coastal wetland (Gialova Lagoon) in connection to groundwater use for irrigation and water supply (drinking water).
- Groundwater and river water availability in connection to nutrient loads from agriculture and local settlements (catchment inputs).
- Coastal lagoon quality in connection to nutrient loads from catchment.
- Fish health in connection to the Mean Annual Salinity of the lagoon.

The Land Uses sub model is used to analyse

- How the gradual transition from conventional to integrated and eventually to organic farming could benefit the sector and lead to improved water quality and benefit biodiversity;
- Tourist development pressures on land uses;
- Increased water demand;
- Area attractiveness in relation to landscape and nature characteristics.

2.2.2.1. Sub-model 1: Wetland salinity regulation and enhancement of ecosystem services

In Figure 9 we present an overview of the selected inputs and the final structure of the operational model.

The calculation period for the wetland operational model is from 2020 to 2100, and it is applied at the Tyflomitis-Xerolagados catchment area (part of the Greek case study). The physical characteristic of the groundwater aquifers (e.g. size, geology, discharge to adjacent aquifers) are imported as fixed values based on available information from previous studies in the area (ENVECO, 2008) and GIS analysis. The climatic conditions and their change in time are based on projections from the XENIOS project from 2013, based on the A2B scenario of the IPCC.

The groundwater abstraction to cover the irrigation demand, is a model input specified as abstraction per well. The current value is based on available information from previous studies (ENVECO, 2008, Padazis, 2018). The effect of climate change (CC) on irrigation demand is closely coupled to the effect of CC on evapotranspiration (ET). The groundwater abstraction for water supply (as drinking water) is a model input which is based on population and tourism trends (calculated by sub model 2). The percentage of the water supply which is linked to the Tyflomitis aquifer is based on available information from previous studies (ENVECO, 2008), and it is validated in communication with the local water agency (during the second MAL in March 2020). The fractions for the freshwater inputs into the lagoon are estimated based on field observations by experts on site.

On an annual basis, the Mean Annual Salinity in the wetland is dependent on fresh-water and saline-water inputs/outputs. In the model we assume that the lagoon volume is not changing on an annual basis. The value of the current (2020) salt mass was estimated based on previous work (Manzoni et al., 2020) and current measurements (NEO stations). The hypersaline ratio is a ratio which compares the lagoon salinity with the sea salinity which is a constant. For the fish tolerance ratio, we used the salinity preferences of seabream, a species that prefers water bodies with relatively high salinity, and has an optimum between 30 and 40 g/L. For the aquatic vegetation ratio, we used the tolerance of reed (around 15 g/L).

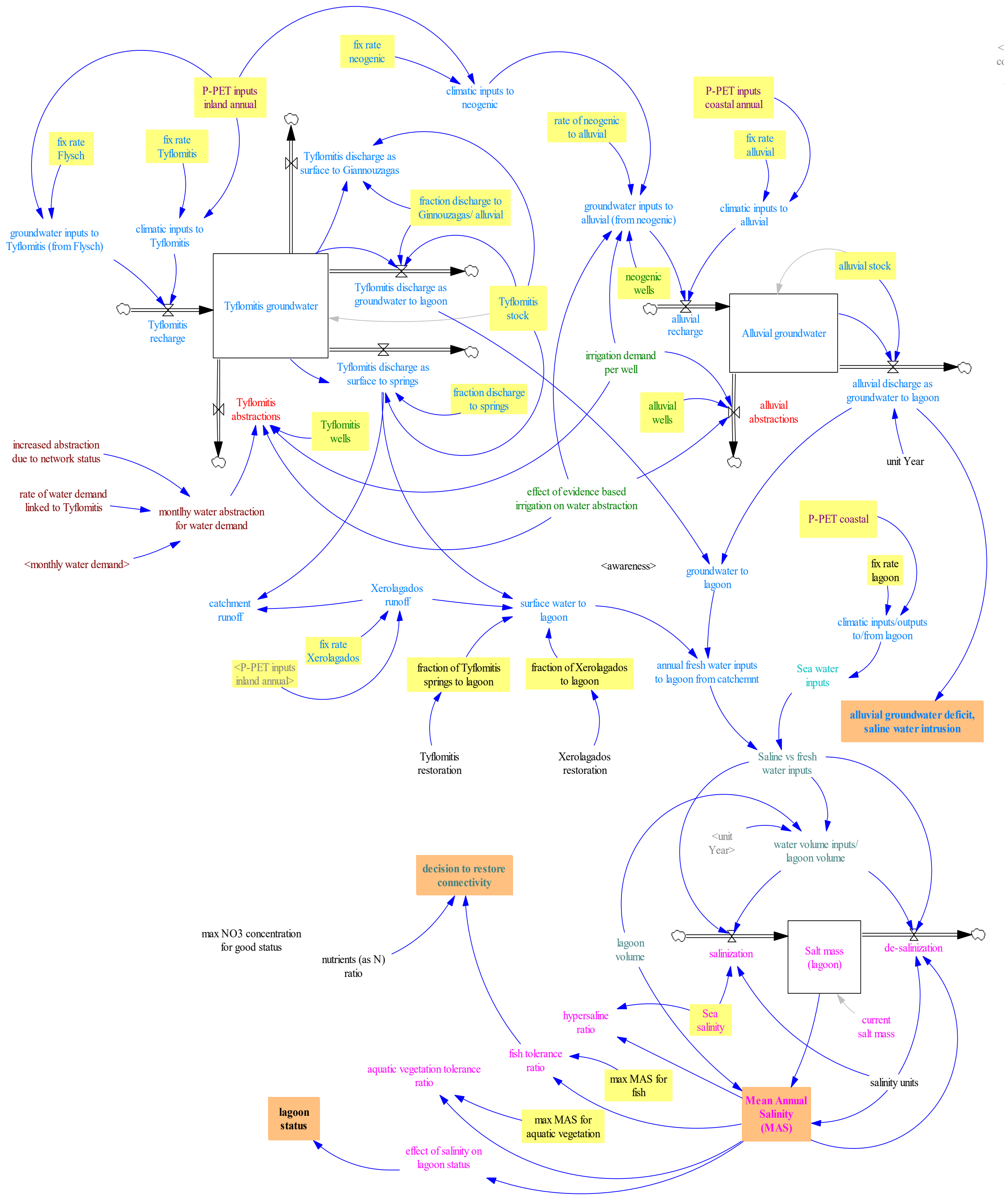


Figure 9: Wetland – Water operational sub model for the Greek case study. Blue for variables linked to groundwater and surface water. Light blue for variables linked with sea water. Teal for variables linked to wetland water. Pink for variables linked to wetland salinity. Green for variables linked with agriculture. Dark red for variables lined to water demand for municipal use. Purple for variables linked with climate (precipitation, evapotranspiration). Variables in a yellow box are inputs in the system. Variables in an orange box are KPIs.

2.2.2.2. Sub model 2: Shift from conventional to integrated farming

The development of the pilot stock-flow model for the shift from conventional to integrated farming, was to a large extend based on the variables and the connections described in the relevant CLD (Tiller, 2021). However, where the initial CLD only referred to organic farming when creating the Pilot SD model (Viaene, 2020) the model was extended to include integrated farming as an intermediate step for the transition to organic farming. Furthermore, the model has been simplified and adapted from the pilot version presented in D13 following discussions with experts and stakeholders. However, the main concepts remain the same.

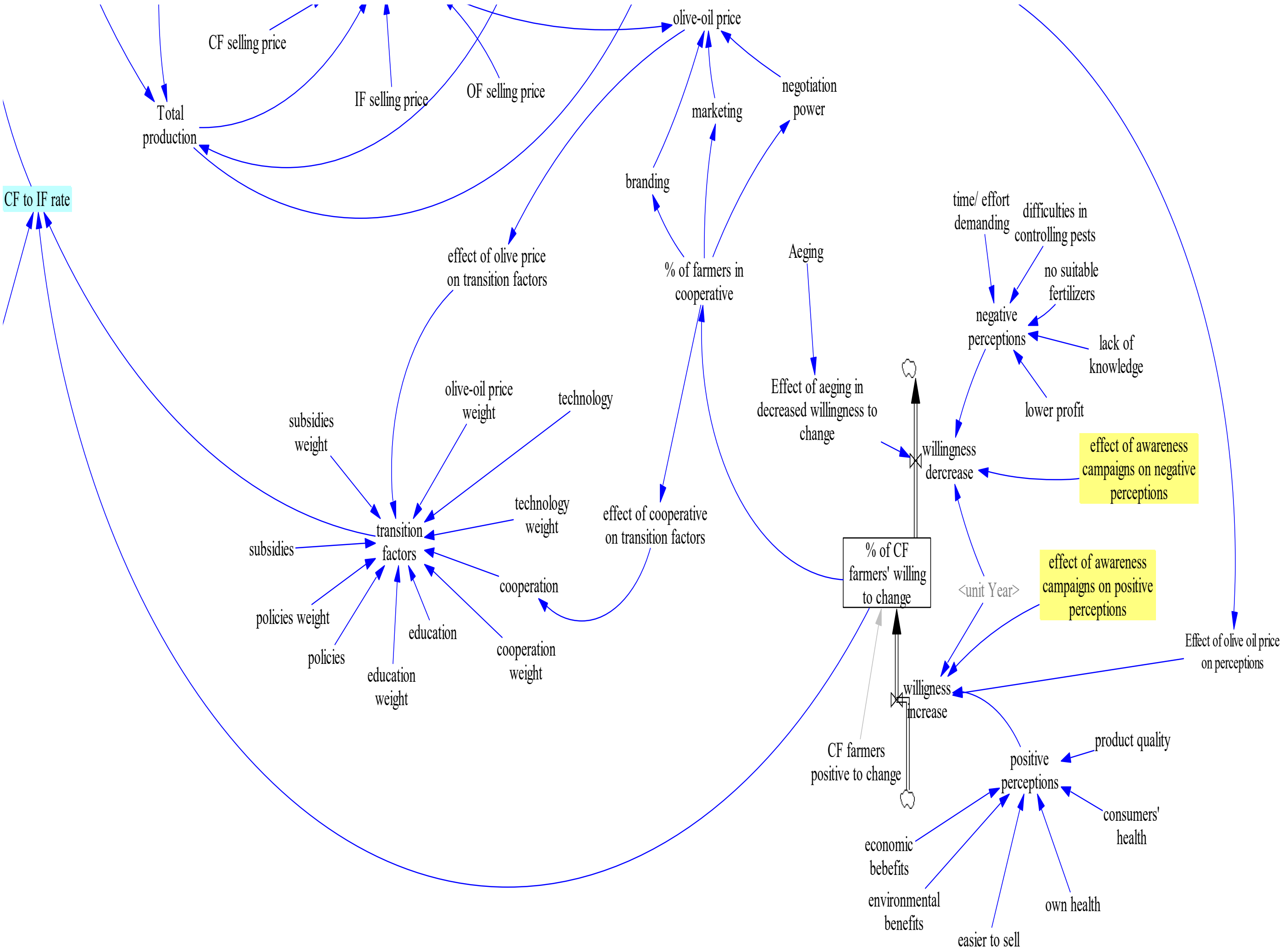


Figure 10: Part of Sub model 2 A shift from conventional (CF) to Integrated Farming (IF) showing the factors affecting the rate of change from CF to IF.

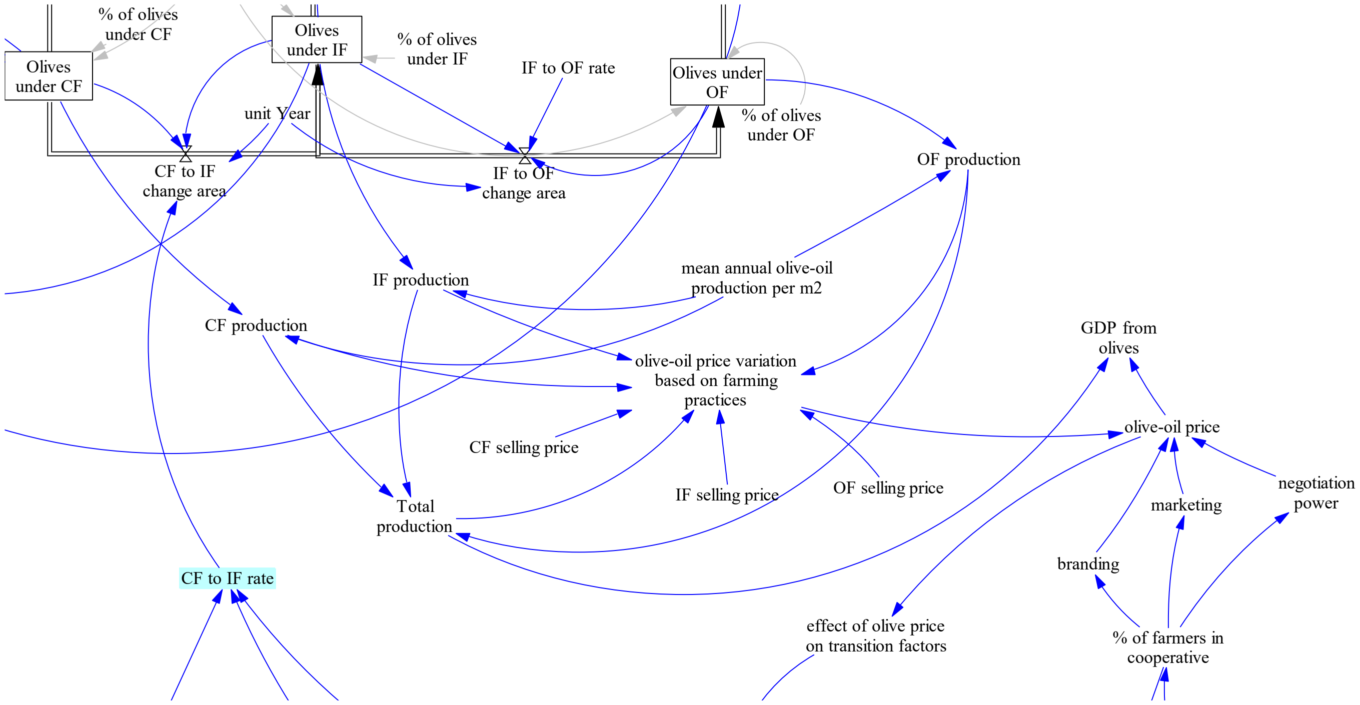


Figure 11: Part of Sub model 2 A shift from conventional(CF) to Integrated Farming(IF) visualising the effect the shift can have to the price of olive oil

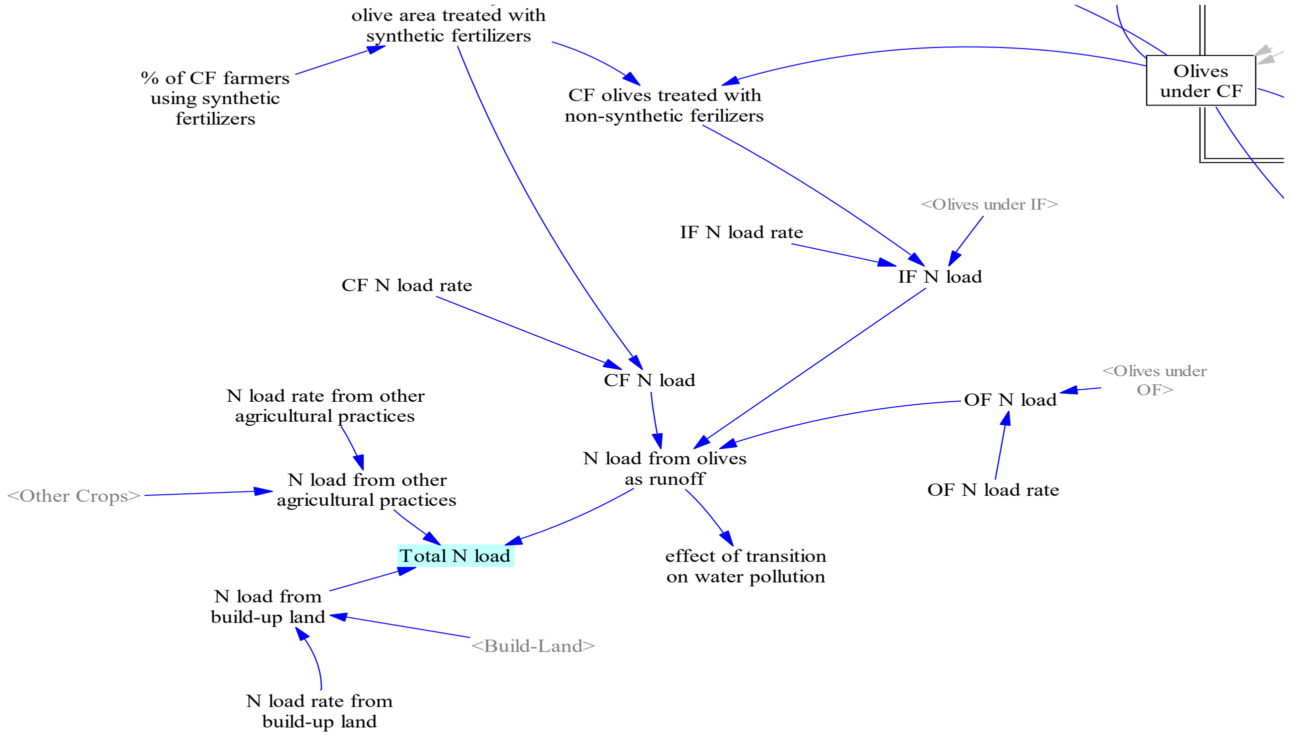


Figure 12: Part of Sub model 2 A shift from conventional (CF) to Integrated Farming (IF) showing the effect the shift can have to the total N load in rivers (The Value is then used in the Water Model to calculate Status).

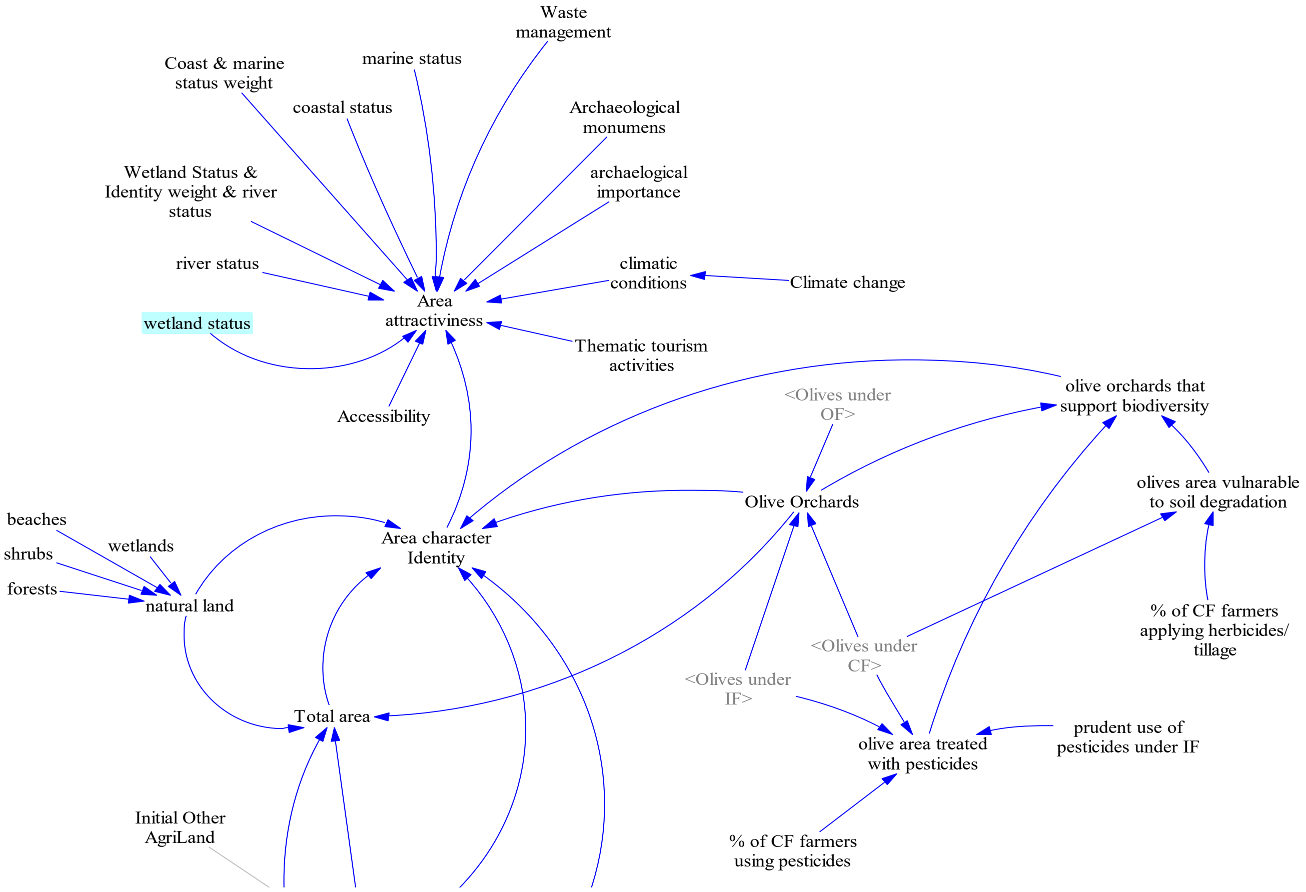


Figure 13: Part of Sub model 2 A shift from conventional to Integrated Farming showing the effects of a successful shift on the olive orchards biodiversity, the character of the landscape and the area attractiveness (The parameters are also used in the tourism sub model).

The calculation period for model is from 2020 to 2100, and the period has been chosen to follow the timeline of the water model, whose values are very much dependent on data availability, and include climatic parameters. The values used account for calculations of trends and changes that have happened in the area during the last 10 to 20 years. In our study area organic farms contain on average 185 (±55) trees/ha and produce on average 1090 lt of olive oil per hectare, while conventional farms contain about 210 (±75) trees/ha and produce on average 1140 lt/ha (Berg et al., 2018, extended information in Engström (2018). Under integrated farming, we assume that the per hectare number of trees and olive-oil production will be optimized to values between those mentioned above. Given the small size of the farms the only viable option for the adoption of sustainable farming practices (integrated and organic) is through a co-operative. The values and weights assigned to the willingness of the farmers to change their practices in the model are based on discussions with the stakeholders and on previously published research, which was conducted in the area using one on one interviews and questionnaires (Berg et al., 2018, extended information in Salguero Engstrom, 2018). The percentage of farmers willing to change is clearly an important stock in the model (Figure 10) and is affected both by endogenous (olive oil price) and exogenous (policies) changes. Besides the factors that affect the farmers' decisions the rate of change from Conventional to Integrated and then to Organic farming is also affected by a number of transition factors (policy, education, available technology, cooperative effect). The importance of each value has been ranked according to stakeholders' preferences.

Cooperatives will play a major role in providing know how and supporting agronomists for full time farming consultation to all members, supporting the application of smart agriculture and relevant data management with support from academic experts, take over the task of branding, marketing and promotion under the guidance of relevant expert, resulting in a better quality produce that could be place branded, in which case the olive oil price could be up to 5 times higher than it is now, as it was mentioned by local experts. Factors affecting the oil price in the model are shown in (Figure 11).

Under integrated farming, the use of tillage and herbicides is not allowed, thus this transformation should reduce the risk of soil erosion and eliminate the use of glyphosate in the farms. With regards to pesticides, an evidence-based approach could reduce the amount of pesticides per hectare, also decreasing potential residues in olive-oil and improving its quality. Fertilisers are also based on naturally derived products instead of synthetic ones. The above combined could decrease agriculture run-off and leakage (Figure 12) with benefits to the wetland ecosystem and increase the capacity of the farms to support biodiversity, like organic farms. However, the use of pesticides, even when more prudent, will still pose a threat to biodiversity. Increased diversity in the farm could be branded to increase the marketing potential but also support agritourism (Figure 13). Water consumption for irrigation could be reduced to optimum since it will be based on data availability on soil and tree needs. To ensure the brand name of Sustainable Messinia and high-quality olive-oil, a strong cooperative, could increase the demand of high operation standards of olive-mills, excluding operations that still pollute the rivers. The operation of this type of olive-mill could be controlled by the relevant authorities.

As more land will be under integrated farming, this will pave the way for branding the area characteristics, adding to final selling price. This could increase food security in terms of a steady and sustainable olive-oil production, from farm to fork. Under the current situation with Covid-19, and possible similar threats in the future, increased food security may become a prerequisite for consuming and trading, and the sector runs the risk of being left outside the market if no actions are taken.

According to our stakeholders, bulk exports make up almost 90% of the total exports. Under integrated farming and strong cooperatives, this huge amount of olive-oil could be branded, marketed and promoted to meet the needs of the global market, with increased profit for the farmers. A steady supply of the market, a prerequisite in trading according to local experts, could be achieved via the operation of cooperatives who should also take the task of branding, marketing and promotion based on relevant experts. The olive-oil price is expected to continuously rise due to better branding, marketing, promotion and negotiation power and fewer bulk exports.

2.2.2.3. Sub model 3: Shift from a seasonal Sun/Sea/Sand tourism destination to a sustainable destination with expansion of the tourism season

In the last 20 years the area reserved for built land or sports facilities has increased by 3.8% (Figure 14). Not surprising the greater of the land use change is happening along the coastline and in areas with views to the sea, the lagoon and the famous beach of Voidokoilia. The expansion includes hotels, and secondary homes, along with accommodation to fit in the employees of the tourism industry.

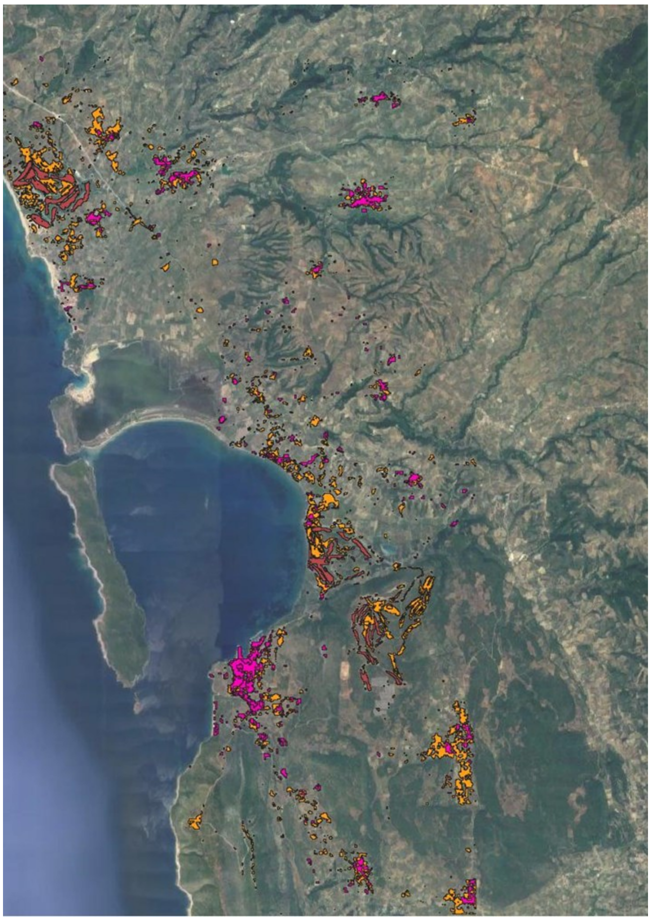


Figure 14: Aerial view of MAL II Case study area showing built up land in 2000 (pink areas) and in 2020 (Orange areas), as well as the site of the two golf courses that were creates in the same period.

In the analysis for the model we decided to maintain a high trend of urban expansion, with a slightly reduced rate however, at the suggestion of our stakeholders, who also include the largest developer in the area (TEMES). The model time horizon is 2020 to 2100 and follows a monthly time step to accommodate for the seasonal stresses on infrastructure, facilities, population and the environment.

Built land and expected tourists are the two STOCK variables in the model. The rate of change of built land is based on the comparison between the total land occupied by man-made buildings in 2000 and in 2020 and from that the new bed capacity is calculated according to the spatial planning legislation that allows for the creation of 100 beds per 20 hectares (which is also the minimum size of land for the development of a new hotel).

In addition to the hotel beds, about 36% of the houses in the municipality are characterised as summer homes or secondary homes. The effects of the increased water demand have been included in the analysis of Model 1, with reference to the protected area of Gialova Lagoon, thus they will not be analysed again with this model. The other problems caused by the temporal increase of population in the area are the increased waste load which for Greece is estimated to be around 1.2 kg per person per day. Similarly, the municipal wastewater facilities receive a load of approximately 150 lt per person per day, while the sewage treatment capacity is limited. With the expected increase in the tourism numbers, these pressures are expected to intensify. The intensification of tourism activities in the area also puts pressure on land use and the landscape identity of Messinia in the long term, which the tourism sector also wants to maintain and improve as a branding characteristic. An analysis of all the variables and equations used to calculate the interactions in the model follows in the Annexes 4b and 5b. This aspect of the Messinian Landscape Identity was also analysed in D13. The possible opportunities offered and their effect on seasonality have been proven difficult to quantify as they are very limited and innovative ideas by the stakeholders have so far been limited to alternative activities (fishing, diving, nature walking) that would be on offer during the same season, with the idea of attracting a different type of tourist and for offering a nature package.

2.2.3. Application: Towards joined forces

2.2.3.1. Application rationale

The integrated MAL02 SD model consists of several views (sub-models), which are separately developed and quantified. In relation to the common vision of the area, some key topics and problems (and their interactions) that we seek to find solutions for in SW Messinia are:

1. The role of cooperatives in achieving the transition from conventional to integrated and eventually organic farming practices (e.g. branding and marketing; negotiation strength; certified production; agrotourism). How is this beneficial for the farmers' well-being, and how can this be enhanced in the coming years (links with future projects and business opportunities)?
2. The expected benefits of the transition from conventional to integrated and then to organic farming are on:
   - the environment (e.g. use of groundwater resources and salinization risk; use of chemical pesticides and fertilisers, water quality),
   - the characteristics of olive orchards (e.g. soil organic content; soil erosion, soil biodiversity, vegetation cover),
   - the well-being of farmers (e.g. cost for fertilising and pest control; olive-oil price)
   - the branding and marketing of local products
   - the attractiveness of the landscape and the promotion of agrotourism
3. The effect of the increase of tourism (and associated feedbacks) on:
   - the environment (e.g. use of groundwater resources and salinization risk, beach degradation)
   - the landscape (olive orchards to built-up land) and associated impacts on the area's character and naturalness.
4. The urgency for wetland restoration actions to prevent the collapse of the ecosystem and to secure and enhance the below:
   - biodiversity conservation and development of eco-tourism
   - fish production and food security
   - area attractiveness and tourism

2.2.3.2. Results and discussion

The developed SD model for the Greek case study is compatible with the requirements of the Water Framework Directive (2000/60) and the defined Regional Management Action Plans for the catchment area.

The model is also compatible with the Strategic Development Program of the Peloponnese Region (Eydpelop) that has been developed as part of the National Strategic Development Framework (ESPA) and the Common Agricultural Policy.

With regards to the protection of the Natural habitats the model supports the implementation of management actions that are being included as proposed actions within the Special Environmental Study and Management Plans for the Natura2000 network areas for the protection of the water and groundwater resources (Skolou and Chlykas (eds), 2021). The measures relate to the conservation objective for monitoring and restoring the hydrological conditions and wetland habitats of the Gialova Lagoon. The proposed measures include the restoration of the hydrological conditions and the wetland habitats (Code of Measure MM25510CJ0301) and the establishment of a management assistance system in Gialova for achieving satisfactory conservation Status (Code of Measure MM25510CJ0201). The actions proposed to restore the natural flows of freshwater back to the lagoon also support the EU Biodiversity Strategy for 2030 objective for the restoration of biodiversity habitats and building local societies' resilience to climate change, as well as the Farm to Fork strategy as the lagoon is being used for fisheries.

With regards to the Farm to Fork Strategy and the future Common Agricultural Policy the model has been designed to measure the progress of several indicators that have been included in the CAP specific objectives identified for Greece (COM(2018)392 final). Examples are the support of viable farm income and resilience of small-scale farmers. This is also connected to farmers' position improvement in the food sector value chain. Water abstraction, soil erosion Nitrogen loads from agriculture have also been identified as specific objectives for the implementation of the Common Agricultural Policy in Greece and are related to farming intensity and the extent of organic farmlands, which have also been identified in the model.
COM(2018)392 final Analytical factsheet for Greece: Nine objectives for a future Common Agricultural Policy (https://ypen.gov.gr/wp-content/uploads/2021/04/PAF-EL_FINAL.pdf)

2.3. Multi-Actor Lab 3 - Norrström and Baltic Sea (Sweden)

2.3.1. Problem scope of the land-sea system

The Baltic Sea is one of the world's largest brackish water bodies, with a land catchment area about four times larger than the sea surface area (Figure 15). In the Swedish part of the Baltic catchment, the Norrström drainage basin (outlined in yellow in Figure 15) and its adjacent and surrounding coastal zones (all together constituting the local MAL3 in COASTAL, and corresponding to the total Swedish Northern Baltic Proper water management district) is a key area with a total population of 2.9 million people. It includes the Swedish capital of Stockholm as well as agricultural and industrial activities and contributes considerable nutrient loading to the Baltic Sea. Because of such loading, the MAL3 archipelago and coastal waters, as many other parts of the Baltic Sea and also many inland waters, suffer from eutrophication and harmful algae blooms (HELCOM, 2018).

Figure 15: The Baltic Sea and its cross-boundary catchment area (outlined in red) with the Swedish Norrström drainage basin (outlined in yellow). Source: HELCOM, 2018.

Such water quality and ecosystem status problems, resulting from continuous excess nutrient (nitrogen and phosphorus) inputs to inland, coastal and marine waters in MAL3 (HELCOM, 2010), are recognized since decades but management results remain insufficient despite various international agreements and environmental regulations applied on local/national and regional/international levels (Destouni et al., 2017). Figure *16* shows the evolution of annual nutrient inputs to the Baltic Sea, with increasing trends mainly between the 1950s and the late 1980s for both nitrogen and phosphorus and decreasing trends thereafter but with loads still remaining above environmental targets. The source attribution pie charts in *Figure 16* include both point and diffuse (current and historical) anthropogenic sources (HELCOM, 2018). Policies and regulations to reduce nutrient loads from various sectoral activities by 50% were first developed at national and international level already by the 1988 HELCOM Ministerial Declaration (HELCOM, 2007).

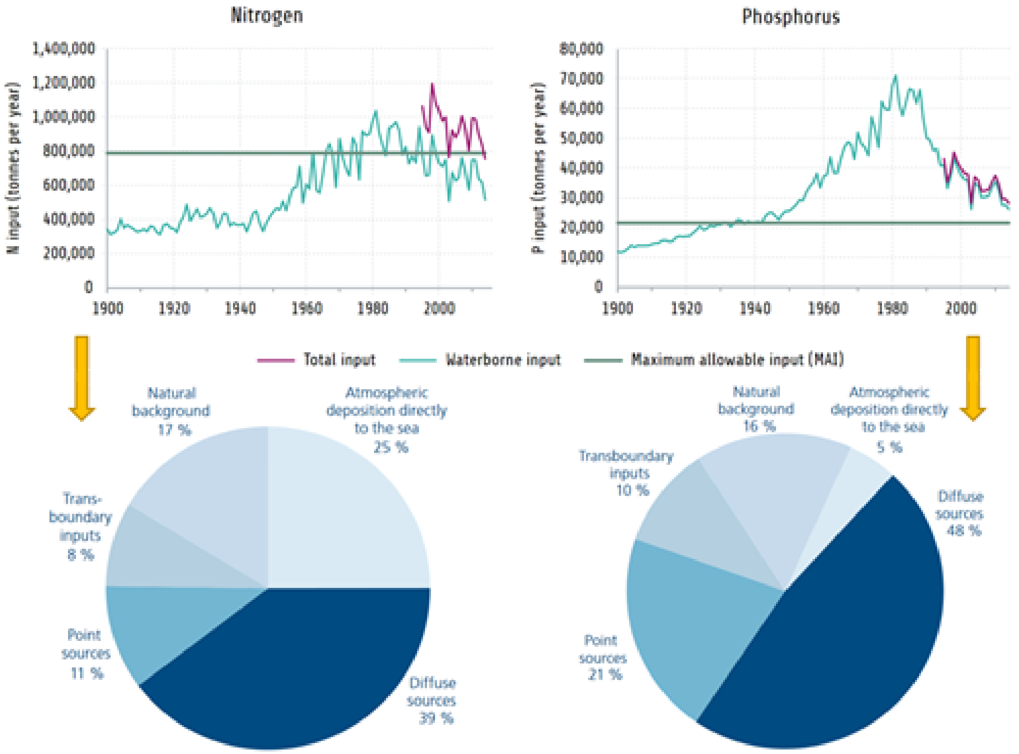


Figure 16: Evolution of annual waterborne and total nutrient loads (of nitrogen and phosphorus) to the Baltic Sea during 1900-2014, and their source attribution for nitrogen (left pie chart) and phosphorus (right pie chart). The maximum allowable load levels in the graphs refer to targets in the Baltic Sea Action Plan (2007). Point sources on the pie charts include both coastal and inland point sources, and transboundary inputs include both point and diffuse sources. Sources: HELCOM, 2010 and 2018.

Since the 1980s, nutrient loads into the Baltic Sea have decreased (graphs in Figure 16), however, they are still greater than the targets agreed for reductions of both nitrogen and phosphorus (HELCOM, 2018) and maintain less than good ecological status in the Baltic Sea and its coastal waters (Vigouroux et al., 2019 and 2020). The historic large nutrient inputs on land also indicate an accumulation of nutrients over time in soils, slow moving groundwater, and sediments that may now be continuously released into the mobile water that flows from land to the sea, in addition to the currently active source inputs on land; the continuous excess loading above targets into the sea over the second part of the last century also implies such excess accumulation within the coastal and marine sediments (corresponding to the area below the annual loads and the targeted load levels shown in the graphs in Figure 16). Such nutrient accumulation and subsequent release are referred to as legacy sources, with unclear sector responsibility for mitigating the associated nutrient loads and also practical difficulties in managing such mitigation, which may require other types of methods than mitigation of inputs from currently active sources (Destouni and Jarsjö, 2018).

Furthermore, MAL3 is a clear cross-boundary case, i.e. the coastal and marine eutrophication problems in MAL3 do not only occur and depend on the local/regional processes and nutrient loads of the Norrström drainage basin case, but also on such processes and loads occurring on the macro-regional/transboundary scale of the whole semi-enclosed Baltic Sea and its entire catchment, with the open sea conditions also greatly influencing the local coastal conditions, in addition to the influences of the local coastal catchment on the associated local coast. Coastal nutrient loads around the whole Baltic coastline are transported across the open sea and contribute to eutrophication and pollution also in other, remote coastal areas. Important mitigation requirements, responsibilities, and opportunities for the transported amounts of nutrients and pollutants across the open sea thus are also outside and over much larger and transboundary scale than just the local/regional land catchment scale of the specific MAL3 coast.

In addition to these land-sea system characteristics, the human population and the associated human land and water uses (Darracq et al., 2005), as well as the regional hydro-climate conditions (Bring et al., 2015a) in the MAL3 case have changed and will continue to change over time. These changes affect directly the water availability and the waterborne nutrient loads from land to the coast and the sea (Bring et al., 2015b), as well as biodiversity and ecosystem services of water systems on land and in the coast (Elmhagen et al., 2015). How to manage these changes and the still required mitigation of nutrient loads to the inland-coastal-marine water continuum in the short and long term is the key problem addressed for MAL3 and the sustainability of its coastal, rural, and urban development, with influences from and implications for sustainable development also around the whole Baltic Sea coast.

2.3.2. Description of stock-flow models

The stakeholder given CLD for MAL3 involves several interactions between natural sub-systems and socio-economic sectors, selected based on their relevance and importance for the addressed water availability, quality and eutrophication problems and associated data/model availability to be further investigated in the MAL3 SD modelling. The integrated MAL3 model consists of the two described sub models, which are separately developed and quantified and then connected through the water flow variables. Any change in these variables due to human activity developments and/or hydro-climatic changes (simulated in sub model 1), will also affect corresponding waterborne nutrient exchanges among (sub-)systems/sectors and their contribution to coastal nutrient loading (simulated in sub model 2). Therefore, some of the outputs of sub model 1 are used as explicit inputs to sub model 2.

For clarity and facilitated editing, different parts of the integrated SD model and their various components are structured in different views in the Vensim software. The integrated SD model takes into account the fundamental physical mass balance constraints as a general condition for the water and nutrient interactions and their impacts on various natural sub-systems and socio-economic sectors. The model simulates these interactions for annual time steps over a 100-year time horizon starting from 2010. Therefore, the initial conditions of the stock variables are defined as long-term average conditions to current time. The boundary conditions are defined as recent-current average conditions of input water flows and associated nutrient concentrations at the land surface and other main component boundaries in the representative MAL3 coastal hydrological catchment. Dynamic changes within the MAL3 land-sea system can then be assessed as results of possible shifts in the defined boundary (i.e. long-term average) conditions as well as of alternative socio-economic development plans and/or environmental regulations in the MAL3 region. The integrated MAL3

SD model can also aid understanding of nutrient legacy source implications for the dynamics of nutrient load evolution in the MAL3 land-sea system.

Figure 17 shows the main feedback loops between key system components (natural water systems and various socio-economic sectors) addressed in the integrated MAL3 SD model. Water availability and quality conditions are controlled by how agricultural activities, urbanization, tourism, and industrialization developments affect surface and subsurface water systems, which in turn feedback water availability and quality shifts, with economic and growth implications, to these sectors. These interactions and feedback loops are also influenced by changes in hydro-climate conditions and by shifts in growth policies and environmental regulations. These interactions were identified as important by the MAL3 stakeholders through the co-developed regional CLD and are reflected as such in the integrated MAL3 SD model.

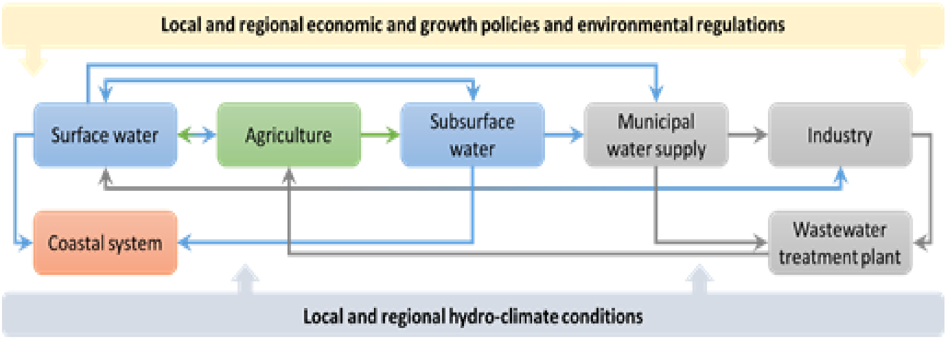


Figure 17: Main feedback loops involved in the integrated system dynamics (SD) model for MAL3. The colour of the arrows for the interactions is assigned based on the box colour of the influencing system component.

2.3.2.1. Sub mode 1: Land-sea inter-sectoral and coastal water exchange

The stock-flow structure of sub model 1 is developed as shown in Figure 18, and presented and explained thoroughly in the deliverable D13(4.2) in WP4 (Viaene et al., 2020). Sub model 1 is fully quantified based on the published peer-reviewed outcomes of an integrated input-output analysis (IOA), specifically for recent-current conditions in MAL3 (Baresel and Destouni, 2005; Cseh, 2009). Natural surface and sub-surface water systems and inland/coastal sectors are considered as stock variables. Inputs to sub model 1, such as precipitation and CCWI from adjacent aquifers, are defined as auxiliary variables with their values being imported to the sub model from a connected excel file including all the values of all input variables to each sub model. Sub model outputs, such as evapotranspiration, water outflow to the coast, proxy of seawater intrusion risk, and CCWE through drinking water and goods are also defined as auxiliary variables with their values calculated based on stock and/or other auxiliary variables. The first three outputs (evapotranspiration, water outflow to the coast and proxy of seawater intrusion risk) are examples of key performance indicators (KPIs) from sub model 1 used to quantify and compare main scenario and roadmap implications in terms of natural system changes, sectoral developments, and (environmental and economic) policies.

Sub model 1 involves 11 additional KPIs, including the contributions of the surface water system and that of the subsurface water systems to the total coastal outflows (2 KPIs), and the water availability for the various socio-economic sectors (9 KPIs) included as stock variables in the sub model. Thus, the outcomes of sub model 1 will be evaluated in terms of, in total, 14 KPIs for various water-related changes and their impacts and implications for different sectors and the overall MAL3 land-sea system behaviour. These KPIs are shown with blue background in Figure 18. The quantification process for sub model 1 is thoroughly explained in the deliverable D13 (D4.2) of WP4 (Viaene et al., 2020) and relevant quantitative information, data and equations are reported in the deliverable D07(D2.2) of WP2 (Seifollahi-Aghmiuni, et al., 2020).

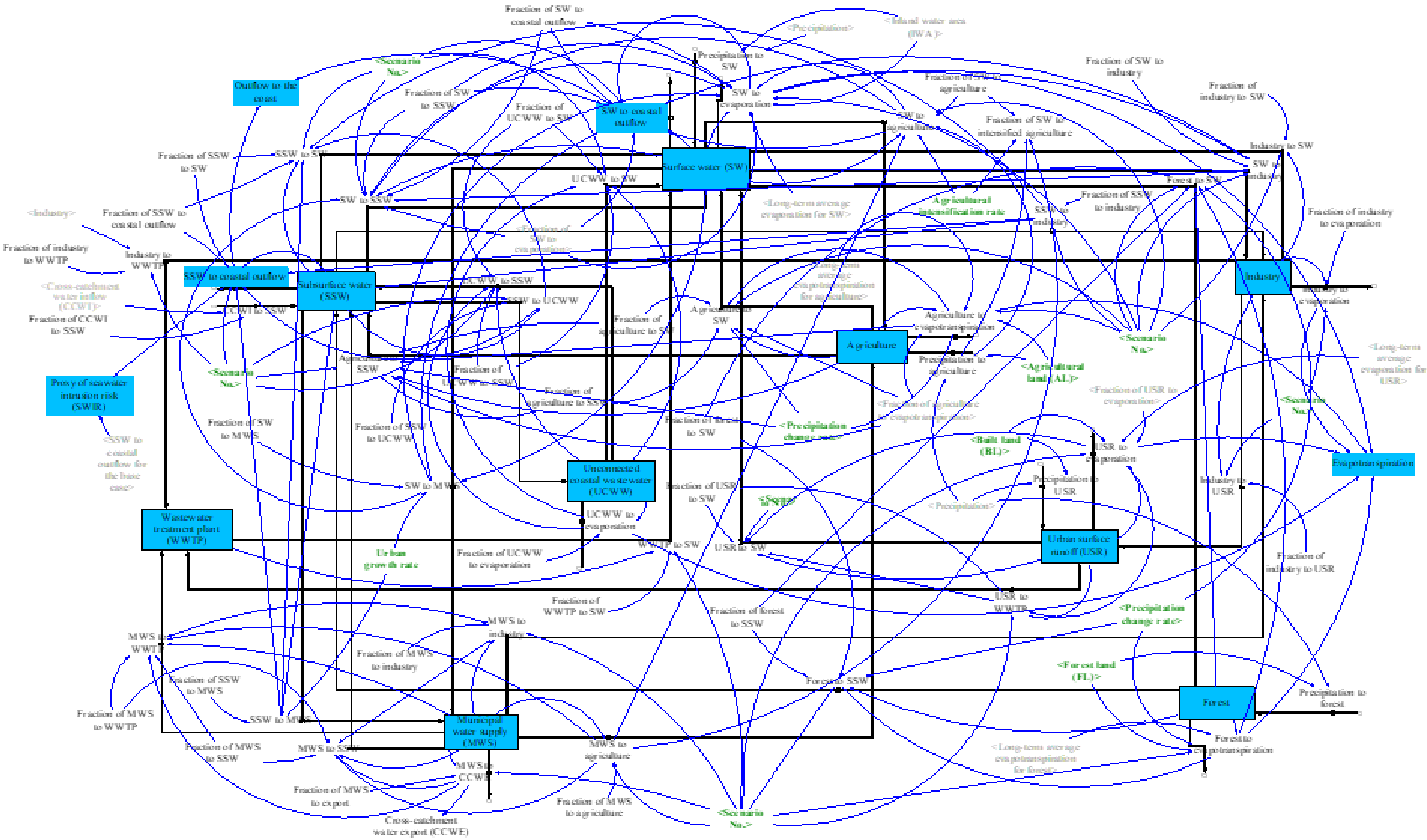


Figure 18: Stock-flow structure of the SD sub model 1 for MAL3. change-development scenarios (green) key performance indicators (KPIs) (blue)

2.3.2.2. Sub model 2: Land-sea inter-sectoral and coastal waterborne nutrient exchange

Since the stock-flow structure of sub model 2 is highly complex with numerous interlinkages and auxiliary variables, a complete layout view of the sub model structure could not be presented in this document. Figure 19 illustrates two parts of the sub model structure for nutrient release from agriculture sector and subsurface water system. It should be noted that nutrient exchanges through natural surface and subsurface water systems are simulated in this sub model by explicitly taking into account the dominant contribution of nutrient legacy sources through nutrient concentration levels in surface and subsurface flows. Similar structures are developed for other inland/coastal sectors depending on their interactions with other system components.

Inputs to sub model 2, such as the average recent-current (possible future) concentration levels of nitrogen and phosphorus in surface and subsurface water and in wastewater treatment plant (WWTP) exchange flows, are defined as auxiliary variables with their values being imported to the sub model from a connected excel file including all the values of all input variables to each sub model. Water flow exchanges among natural (sub-)systems and sectors that are simulated in sub model 1 are also considered as inputs to sub model 2. Outputs of sub model 2, such as nutrient exchanges among natural (sub-)systems and socio-economic sectors and their contributions to the coastal nutrient loads are defined as auxiliary variables with their values calculated based on relevant nutrient concentration levels and water flow exchanges within the MAL3 land-sea system.

Sub model 2 includes 25 KPIs related to the total nitrogen and phosphorus loads to the coast (2 KPIs) and the contributions of surface and subsurface load components to each total coastal load (4 KPIs), and the total nitrogen and phosphorus through flows (discharges from/to) the inland surface and subsurface water systems (4 KPIs), urban runoff (2 KPIs), the green sectors of agriculture and forestry (3 KPIs), WWTPs (2 KPIs), industry (2 KPIs), municipal water supply utilities (2 KPIs), and unconnected coastal wastewater systems (2 KPIs), and the Baltic Sea Action Plan (BSAP) policy indicators for nitrogen and phosphorus (2 KPIs). The outcomes of sub model 2 will be evaluated based in terms of these 25 KPIs in relation to various water- and nutrient-related changes and their impacts and implications for different sectors and the MAL3 region as a whole. Some of the KPIs in sub model 2 are shown with blue background in Figure 19 and Figure 20. The quantification process with associated equations is reported in the deliverable D14 (D4.3) of WP4 (de Kok et al., 2021). Also, quantitative information and data used to quantify this sub model are included in the deliverable D07 (D2.2) of WP2 (Seifollahi-Aghmiuni, et al., 2020).

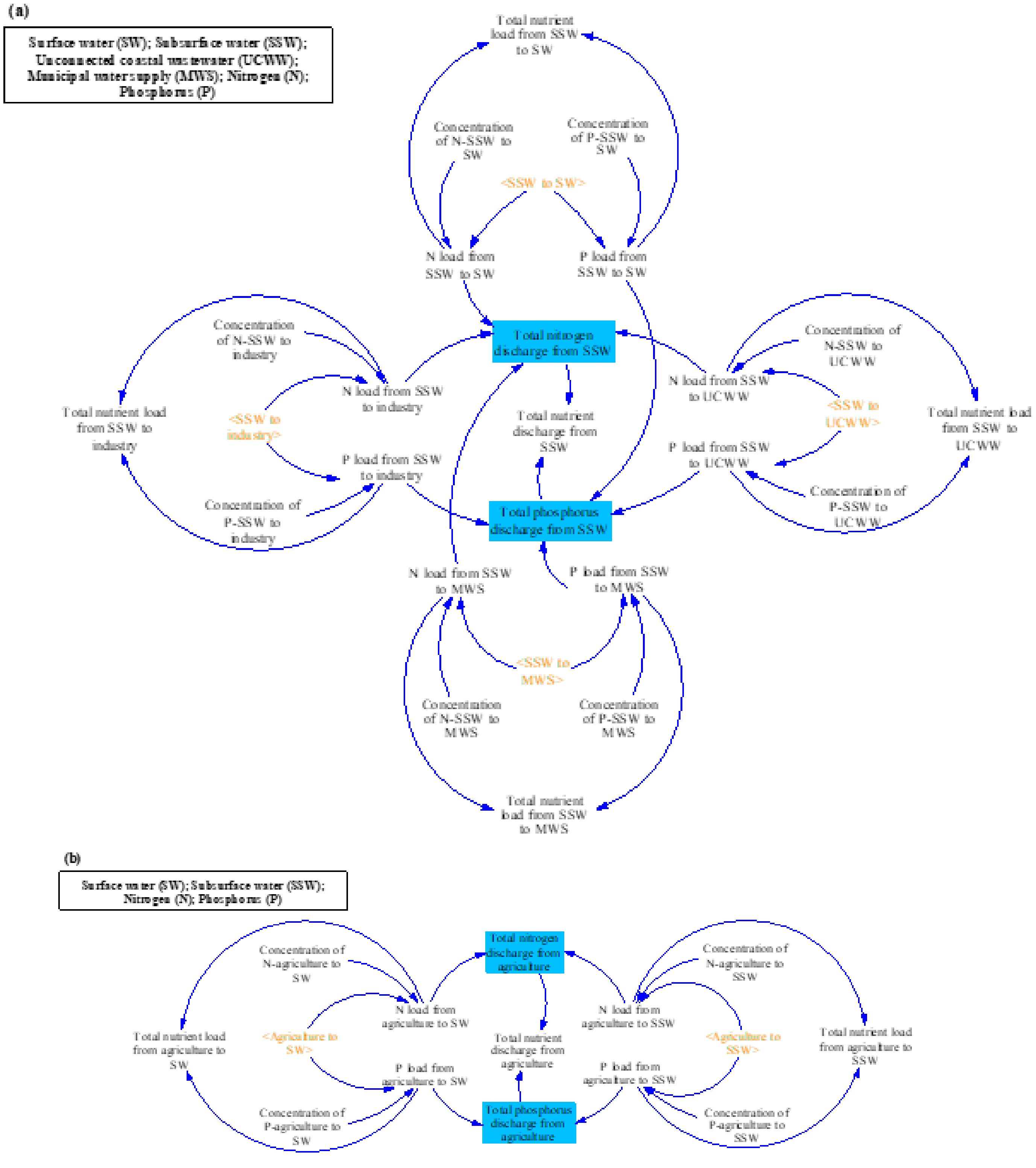


Figure 19: Stock-flow structure of nutrient (N: nitrogen, P: phosphorus) releases from subsurface water system as a natural sub-system (a) and from agriculture as an inland/coastal economic sector (b) to the connected natural sub-systems and inland/coastal sectors in the SD sub model 2 for MAL3 developed in Vensim software. These structures are shown as examples of stock-flow structures developed as part of the SD sub model 2 for MAL3. This sub model is connected to the SD sub model 1 through the variables shown with orange font colour. The variables shown with blue background represent some of the key performance indicators (KPIs) from this sub model.

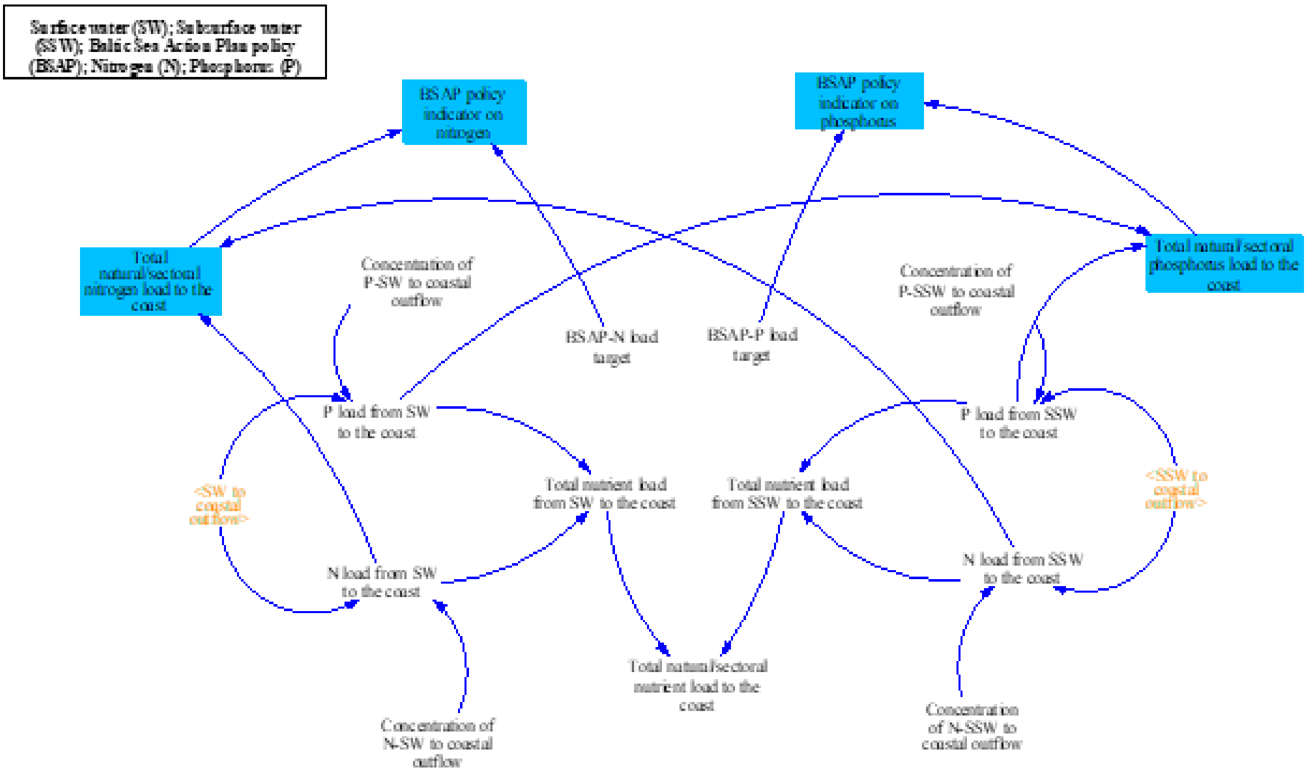


Figure 20: Stock-flow structure of coastal nutrient (N: nitrogen, P: phosphorus) loads in the SD sub model 2 for MAL3 developed in Vensim software. This structure is also connected with the stock-flow structures developed for the inland/coastal sectors as part of the SD sub model 2 for MAL3. The variables shown with orange font colour represent connecting variables to the SD sub model 1. The variables shown with blue background represent some of the key performance indicators from this sub model.

2.3.3. Application: Tackling issues of water availability and water quality

2.3.3.1. Application rationale

The Norrström drainage basin and its adjacent and surrounding coastal zones (MAL3) is a key area in Sweden with a large human population for Swedish conditions. It includes the Swedish capital of Stockholm as well as agricultural and industrial activities and contributes considerably to the nutrient loading to the Baltic Sea. Due to this nutrient load, the MAL3 archipelago and coastal waters, like many other parts of the Baltic Sea, suffer from eutrophication and harmful algae blooms. Environmental regulations, such as the Water Framework Directive (WFD), which focuses on the aquatic environment on land and in the coastal areas up to 1nm, and international agreements such as the HELCOM Baltic Sea Action Plan (BSAP), which focuses on the Baltic marine environment, put in place decades ago have still not managed to decrease the nutrient loads from land sufficiently (Destouni et al., 2017) to combat severe eutrophication, hypoxia and algal bloom problems in the coastal and marine waters of the Baltic Sea.

The systems dynamics (SD) model for MAL3 tackles issues of water availability and water quality - including also risk of seawater intrusion (SWI) further into fresh coastal groundwater - related to the WFD and BSAP, and consists of two sub-models, with one representing water quantity/availability and SWI issues and the other water quality issues related to waterborne nutrient (phosphorous and nitrogen) loads through the MAL3 drainage basin and groundwater and surface waters and further to the coast and sea. We have used this model to simulate three management alternatives related to the MAL3 business roadmap, considering reduction of nutrient concentrations and loads leaching from agricultural soils, reduction of nutrient concentrations and loads discharging from wastewater treatment plants, and reduction of surface and groundwater nutrient concentrations and loads to the coast. Simulation results and their policy contexts have been discussed with the MAL3 local partners during a meeting on June 2nd.

2.3.3.2. Results and discussion

Simulation results show that measures targeting only reductions in nutrients leading from agricultural land or discharging from wastewater treatment plants yield only limited, insufficient reductions of nutrient loads to the coast. In contrast, measures targeting downstream reductions in the nutrient concentrations and loads borne by the groundwater and surface waters – including from both currently active sources, like ongoing agriculture and wastewater discharges at the surface and from remaining legacy sources in soil, slow-flowing groundwater and sediments - are required to achieve significant reductions in nutrient loads to the coast. Thus, the most important outcome of our model is that legacy nutrient sources, which are diffusely distributed throughout the MAL3 drainage basin, are the main contributors of current nutrient loads to the coast, for both nitrogen and phosphorus. Addressing and mitigating the nutrient concentration and load contributions from these sources is therefore essential and requires integrated management actions throughout the whole MAL3 drainage basin.

Implications of these results for management measures have been discussed with the local partners in the context of Swedish policy and actions to achieve the WFD and BSAP objectives. Reducing nutrient concentrations in and coastal loads groundwater and surface waters, and their environmental effects on these and the receiving coastal and marine water environments requires combined implementation of different types of water management measures on land. These may, e.g., include combined wetland restoration, construction and effective placement, more efficient fertilizer use, construction of different types of reactive barriers, and mussel and seaweed farming at the coast. Further assessment is needed of the effects of various potential combinations of such management measures at different local conditions in the drainage basin and at the coast, as well as improved communication and collaboration between the different sectors involved. Policy changes are also needed to incentivise these measures. Increasing nutrient recycling would be particularly valuable for phosphorus, which is becoming an increasingly scarce resource, for example through mining of phosphorus legacy reserves in soils and sediments, and productive re-use of sludge-based fertilizers from wastewater treatment plants. Establishment of a nutrient market could drive these types of measures, but discussion with local partners in MAL3 indicated that such nutrient market establishment would not be feasible at the regional Baltic Sea scale (of relevance for BSAP achievement) and would not be meaningful at just local scale. Finally, in addition to or as integral parts of such integrated measure combinations, reduction of nutrient leaching or discharges from currently active sources at the surface is still crucial, as the active nutrient inputs today determine the future coastal nutrient loads and associated eutrophication problems of tomorrow in fresh, coastal and marine waters.

More general policy issues related to these outcomes have also been discussed with local partners for the Swedish context. Implementation of integrated combined nutrient management measures throughout the drainage basins on land across Sweden would require a clear and effective national management plan for groundwater and surface waters and the nutrient loads that they carry to the coasts. However, the two cycles of Swedish Water Management plans so far have not succeeded in sufficiently reducing nutrient loads that cause eutrophication in Swedish inland and coastal waters. Proposed Swedish Water Management plans for the third cycle (2021-2027) have been prepared by the five Swedish water management authorities and undergone public consultation, but were met with heavy criticism, including by the overarching Swedish Agency for Marine and Water Management, charged with overseeing, coordinating and reporting to the EU about these plans. In addition, the needed integrated measure combinations would also require effective communication, coordination and planning between municipalities, which is also sorely lacking in Sweden. Important reasons for this include that: (i) Swedish agencies have no authority over other agencies, including the municipalities that ultimately have to take such concrete measures; (ii) neither the municipalities nor any other (type of) agency among the multitude ones that some water/nutrient responsibility fragment in Sweden, has overarching responsibility for carrying out and achieving the water management and program of measures plans; and (iii) there has been no, or far too insufficient funding enhancement for municipalities to advance from a prevailing severe lack of data and expertise resources, and appropriate processes for managing to identify, decide on, and implement the required combined measures. Furthermore, implementation of these measures would also require effective communication between authorities and various economic sectors (agriculture, tourism, forestry…) and among the latter, which may even be opposed to the ongoing implementation of the WFD, e.g., because it is seen to unnecessarily complicate their activities without any evident actual environmental effects.

The emergent dominant role of legacy sources for water quality and eutrophication problems in the MAL3 case, and the policy issues that arise from this, are not specific to this Swedish case. For example, the French ministries in charge of environment and agriculture commissioned a report on eutrophication to guide public policies due to ongoing debates about the driving factors of such problems (Le Moal et al., 2019). This report has found that eutrophication drivers have shifted from point sources in the 1970s to legacy and diffuse sources in the current situation. Thereby, solutions along the entire land-sea continuum are needed to tackle this issue (Le Moal et al., 2019). The crucial role of legacy sources of both nitrogen and phosphorus for groundwater, surface water and coastal-marine water quality and eutrophication problems now calls for changes in management frameworks and policies to account for long lag times from management measure to actual effects, and to apply spatially targeted measures and identify new synergistic uses of legacy resources (Basu et al., 2022).

2.4. Multi-Actor Lab 4 - Charente River Basin (France)

2.4.1. Problem scope of the land-sea system

The part of the Charente River watershed (10000 km²) located upstream, downstream and beyond the coastal zone is under significant environmental pressure from different economic activities such as summer tourism, agriculture, and shellfish farming (Figure 21).

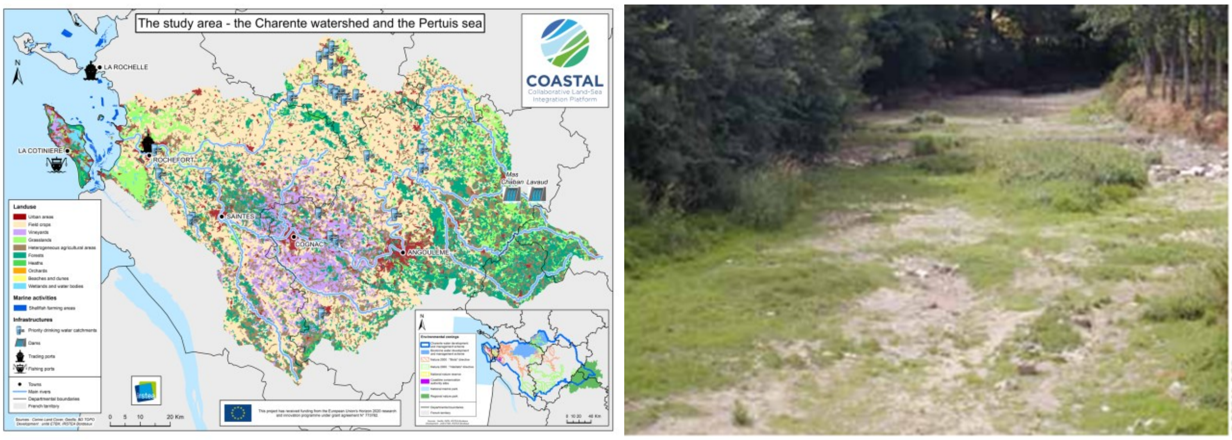


Figure 21: The Charente River basin with illustration of the main concern of this MAL (one tributary of the Charente River in summer).

Environmental issues are even more important as the urban coastal population is steadily increasing, resulting in continued pressure on land availability in rural areas, protected areas and the many salty or freshwater wetlands. The use of water resources for drinking water and irrigation, as well as for the preservation of a minimum instream flow to protect aquatic ecosystems requires large volumes of water. Water resources are limited, and this limitation is aggravated by the effect of climate change (droughts in spring and summer). This situation, although quite common in France and Europe, is exacerbated in the Charente catchment area. Pressure on water resources affects both quality (i.e., pollution by nitrate and pesticides) and quantity (impact on natural environments and availability of drinking water) of these resources. In this area, activities carried out by agriculture with irrigation of crops (mainly maize), use of nitrate (in particular with cereal crops) and pesticides (notably on vines used for Cognac production) and by domestic users have a significant impact on water resources. Changes in farming systems and more sustainable practices are the only solution to improve the quality of freshwater resources. This impact is felt downstream, in coastal areas, in significant sectors for the local economy such as shellfish farming and tourism.

The preservation of coastal water quality (salinity, planktonic and benthic production) is of utmost importance for shellfish farming and professional inshore fishing. In addition, due to the flatness of the coast, the presence of important wetlands increases the effects of climate change (sea level rise) and the possible soil salinization of coastal farming areas. At the same time, the two major ports in the area rely on local agricultural products for a sizeable portion of their business. Any significant change in activities and land use in one part of the territory will impact employment in several sectors and locations of the rural- and coastal zones.

The situation is further complicated due to the continuous increase of residential or immigrant elderly population and of tourists on coastal zones causing important effect on land prices and changes of demand for products and services.

New development opportunities raise questions that are controversial or sensitive. The development of reservoirs could be a means for farmers to access a reliable source of water to irrigate their crops and ensure production of their main export crops (cereals, maize), on which the activity of La Rochelle port largely depends. Opponents of reservoir development argue for the potential imbalance of the water cycle and the privatization of water resources which is a public good. Another new opportunity likely to cause disruption is a shift from present farming systems towards more environmentally friendly systems with less water-dependent crops. The development of diversified crops could be a real opportunity for the second merchant port along the Charente River (Tonnay-Charente), which, due to its more upstream location, is only accessible by smaller vessels.

2.4.2. Description of stock-flow models

The model considers 5 sub models. All these sub models interact and share at least one common variable in the integrated model. The water sub model (Sub model 1; 2.4.2.1) plays a central role, as main vector of land-sea interactions. The integrated model can be used to assess land-sea interactions in a systemic way. As an example, in a scenario where population is growing and with favourable conditions for change of agriculture towards more sustainable practices, the model can evaluate the effect of these changes on the river flows and its positive impact on oyster's production downstream on the coastal zone. However, if in parallel the capacity of wastewater treatment plants (WWTPs) does not increase, these impacts may be hampered by WWTPs overloads. Thus, by highlighting the interactions, the model helps its users think about the system as a whole and consider how changes in one part will affect other parts.

2.4.2.1. Sub model 1: water and wastewater treatment

The water sub model simulates on a monthly basis the water cycle with seven compartments for the water quantities (Figure 22): *water in soil*, *groundwater*, *surface water*, *water streams* (Charente River and tributaries), *water in marshes*, *dam storage*, *reservoirs* and wastewater treatment plants (*coastal WWTP* and *rural WWTP*). Dedicated stock variables represent these quantities of water in Mm^3 (million cubic metre). Over time, these compartments exchange water through different simplified physical processes. Flow variables represent these exchanges in Mm^3/month. Once the flows are calculated, two main indicators are derived:

- the water streams flow, in m^3/s, to maintain above a threshold limit;
- the concentration in trophic resource in the estuary, in mg/m^3, necessary for shellfish production.

In addition, the sub model calculates the amounts of water that can be withdrawn and used for domestic purposes, industry, irrigation and reservoirs.

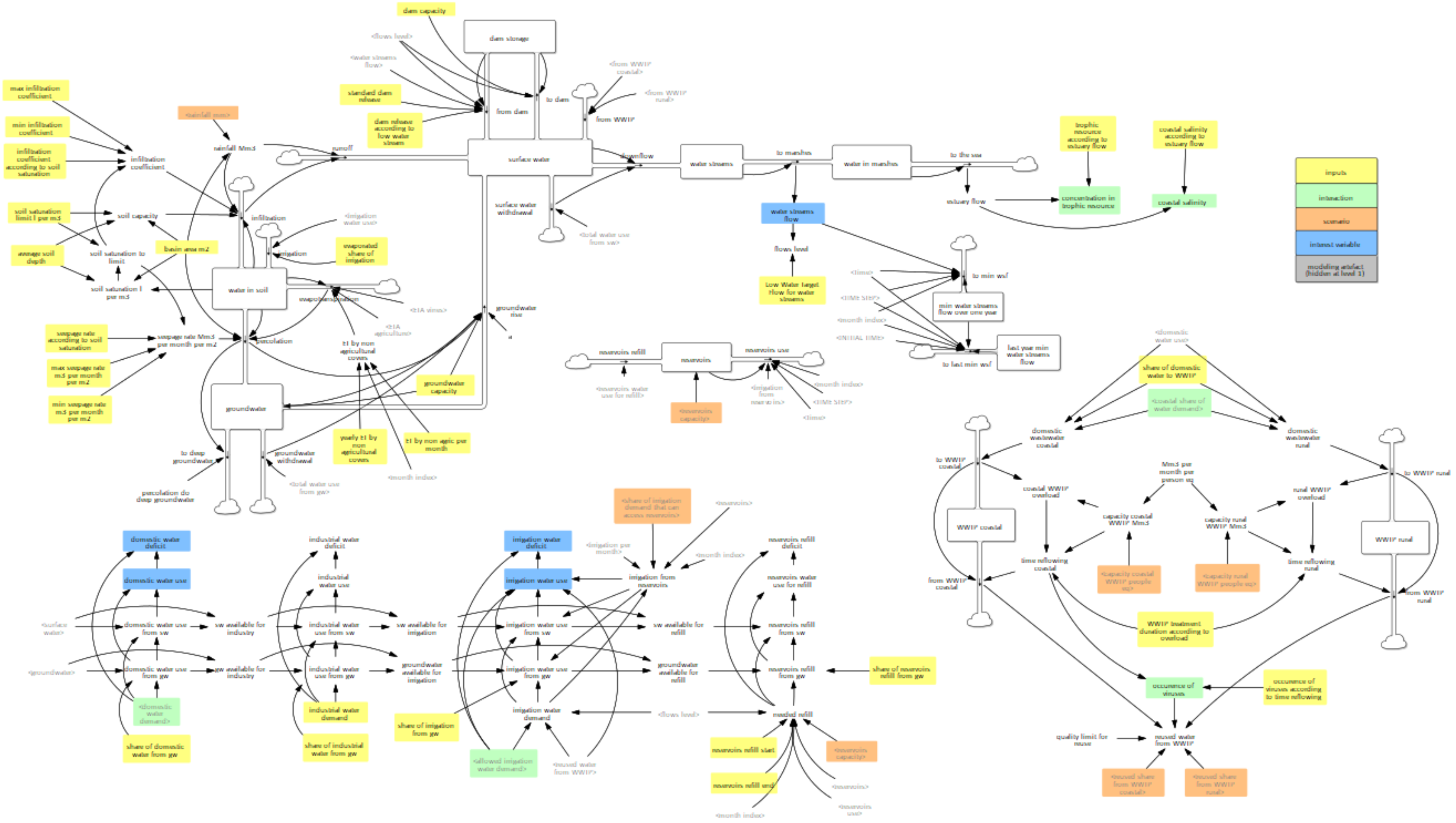


Figure 22: Overview of the SD water sub model

2.4.2.2. Sub model 2: Shellfish farming

The shellfish farming sub model (Figure 23) simulates the *total number of oysters* grown in the coastal area and their average *quality index* over time. The underlying assumption is that all the oysters are of the most selling category, which allows to easily convert oyster numbers to tons, the commonly used unit in data.

Considering a standard three years production cycle, the *total number of oysters* is at time *t* the sum of three stocks: *oysters in first production year*, *second year* and *third year*. Every month, oysters die according to a *mortality rate* per stock, decreasing each stock. Observed data are used for past mortality rates, while future rates are set in scenarios (cf. deliverable 20 “Robustness analysis of policy and business actions”). At the beginning of each year, a fixed number of spats is put in production (*spats input* flow) and increases the stock of *oysters in first production year*. Considering that shellfish farmers grow as many oysters as possible, the yearly *spats input* depends on the available leasing ground management. Hence, it is calculated according to the following variable: the total *authorised oyster farms area*, the *oyster density per bag* each year and the *spats input per sold ton*. At the same time, flow variables transfer the surviving oysters to the *second year* and *third year* stocks. At the end of the third production year, oysters are sold (*to market* flow).

Given the *total number of oysters* and the *available trophic resource* in the estuary, the *cumulative resource per oyster over 3 years* is calculated. This value is used to calculate the *quality index* using a lookup.

The unit price of oysters and the sold amount depend on the *quality index*, which lookups represent. All the marketed oysters are either sold locally (80%) or exported (20%) at an almost double price. To calculate the *oyster gross margin*, the following costs are taken into account: *production*, *transport*, *purification* and *spat purchase costs*. These costs are calculated using average values per sold ton of oysters or per purchased ton of spat. If the missing part of the needed spats that is not captured is totally purchased, the *spats purchase* is equal to the *spats input* minus the *spats capture*. This latter depends on the *available trophic resource* in the estuary.

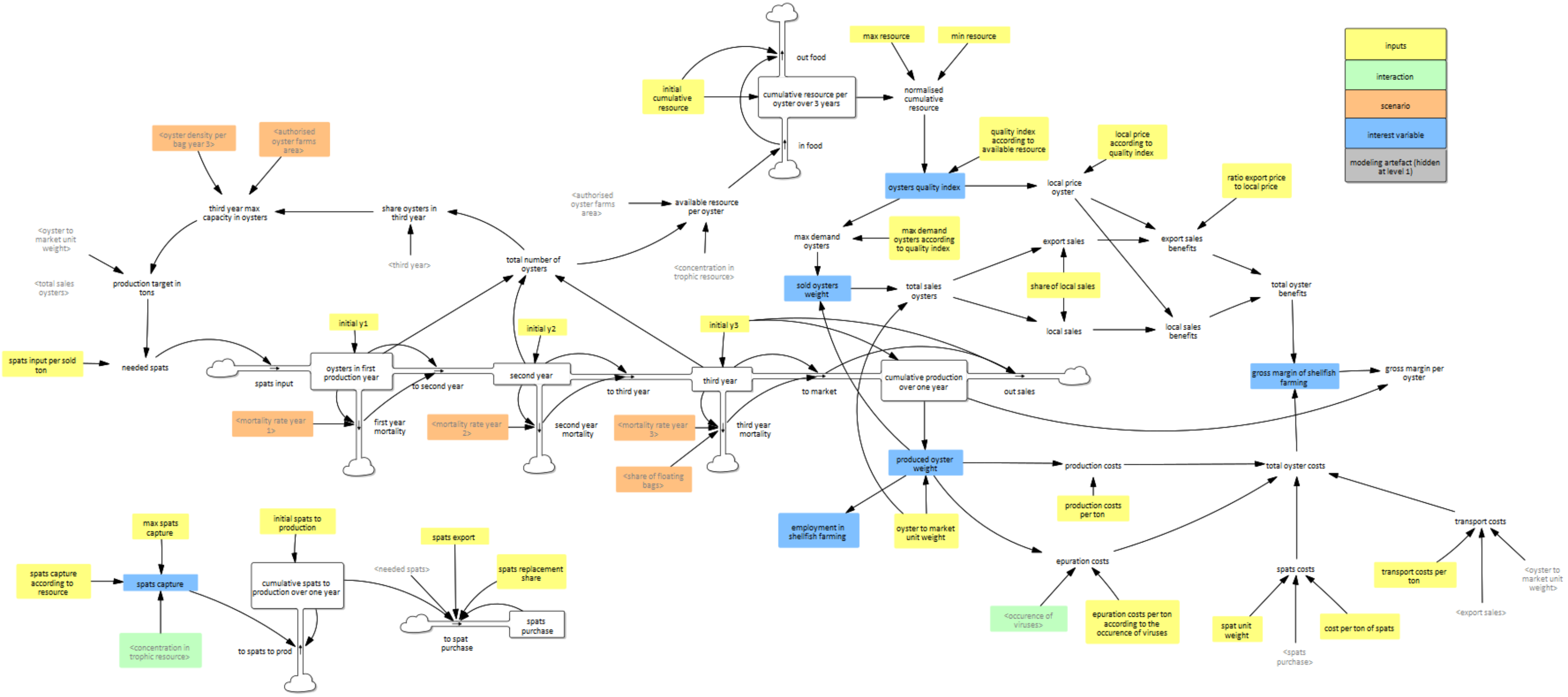


Figure 23: Overview of the SD shellfish farming sub model.

2.4.2.3. Sub model 3: Agriculture

For the stakeholders of the agricultural sector and for MAL4 local partners, there is little doubt that farm practices are changing and will continue to change in the future towards more sustainable farming activities. Actors' main interest lies then in understanding to which extent this change will occur, why and how, in the context of the global evolution of the territory.

Here are some of the questions raised by stakeholders: What share of the agriculture could ultimately be sustainable and how fast could this level be reached? What factors may limit or foster this change? Which innovative actions will help achieve a sustainable agriculture? In this line, the sub model simulates the conversion of areas to organic agriculture. Assuming that this conversion will occur, the factors that may encourage this change are identified and their influence is quantified. Over time, several indicators of impacts (e.g., irrigation water use or pesticides use) and benefits (e.g., the total gross margin) are calculated in order to evaluate the overall effect of the conversion.

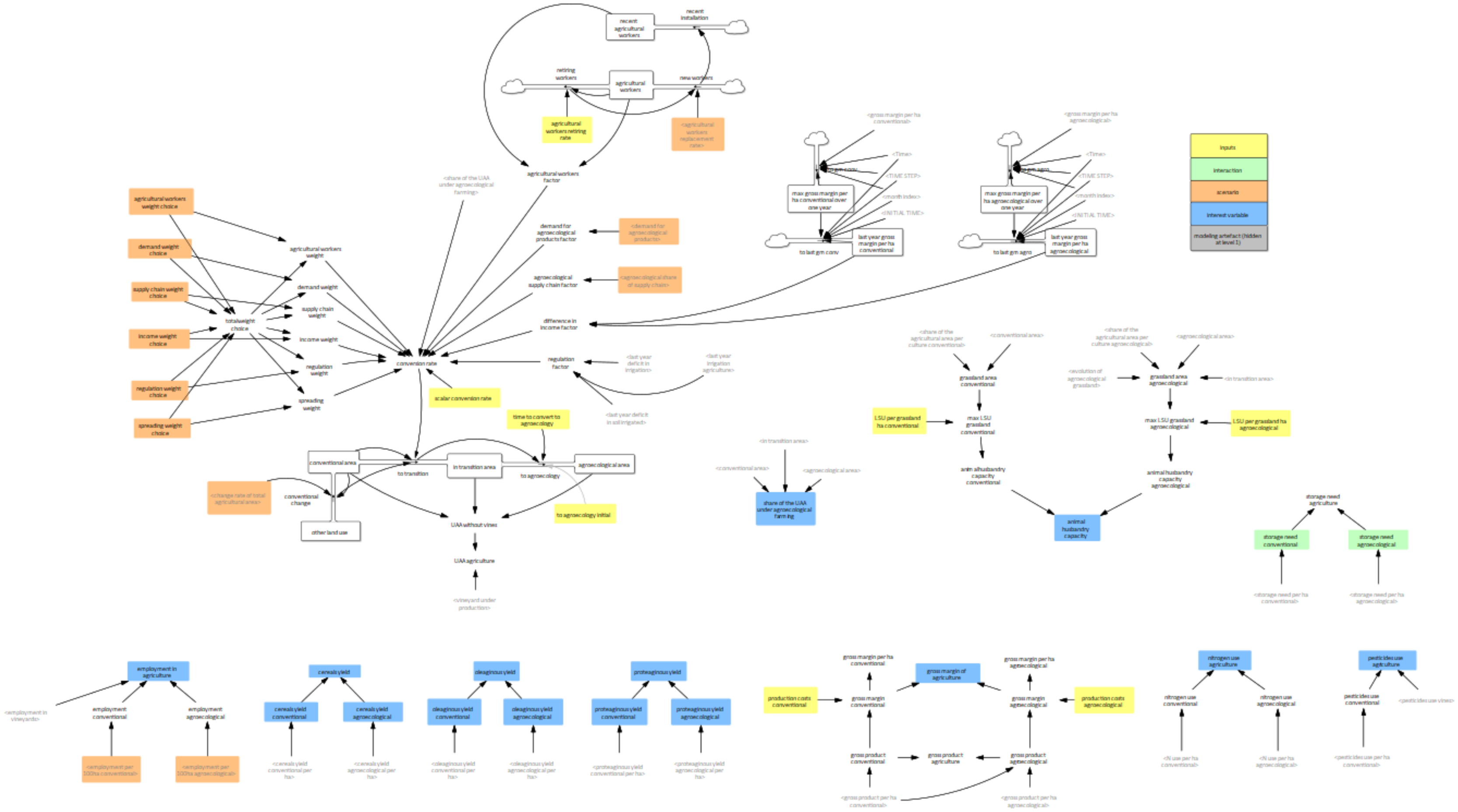


Figure 24: Overview of the SD agriculture sub model.

2.4.2.4. Sub model 4: Infrastructure

The infrastructure sub model includes three parts representing the infrastructures linked with other simulated activities: the storage of cereals over the territory, housing (for residnets and tourists) and roads. Housing constrains the evolution of population and tourism and depens on variables set in scenarios (cf. deliverable 20 “Robustness analysis of policy and business actions”). The two other parts serve to calculate infrastructure needs, considered as investment costs necessary for the sustainable development of the territory.

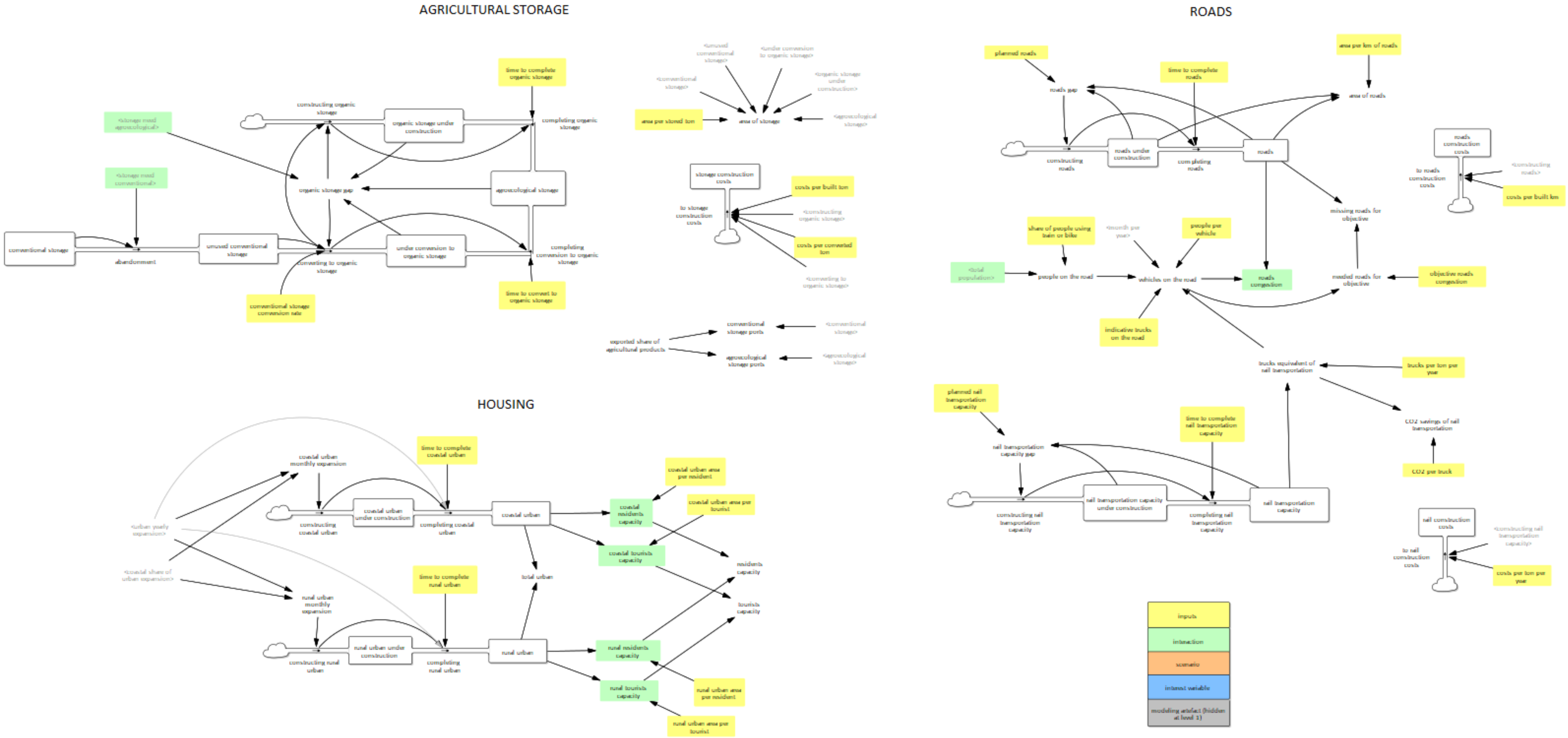


Figure 25: Overview of the SD infrastructure sub model.

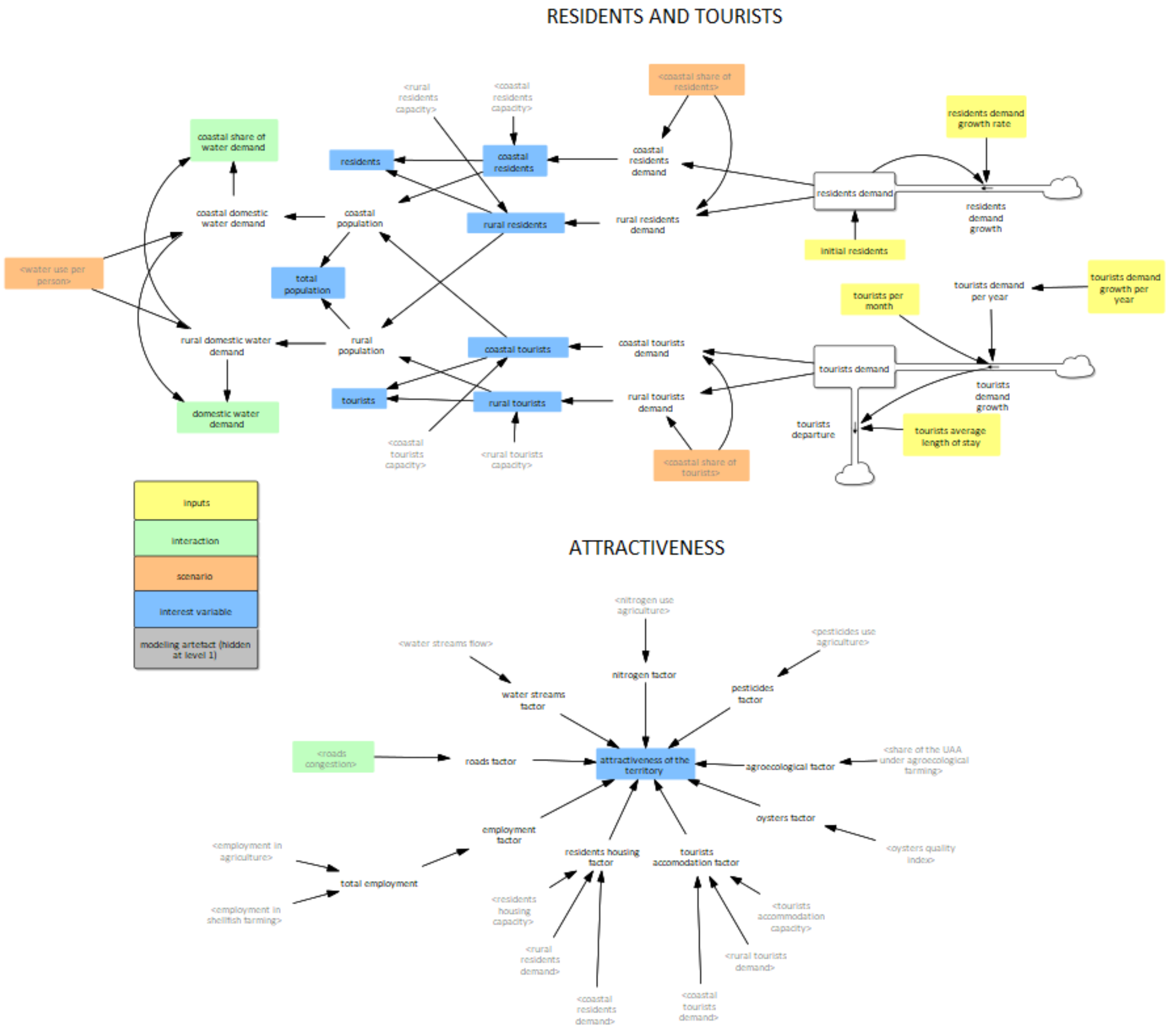
2.4.2.5. Sub model 5: Population and Tourism

This sub model simulates the dynamics of the population over the territory of the case study. The dynamics of the residents' and tourists' populations are driven by fixed growth rates (scenario inputs) and their distribution between the coastal and rural areas depends on fixed shares (scenario inputs).

In the population model (**Error! Reference source not found.**), two stocks represent the total number of *residents* living and *tourists* visiting the area each month. On the one hand, the residential population grows every month at a fixed rate (in % per month). On the other hand, the tourist population fluctuates over the months. While the total number of tourists over a year is set to constantly increase at a fixed rate, this annual population is distributed over the months according to observed affluences, with a peak in the summer months. Also, the number of tourists that can be present at a same time is limited by the *tourist's capacity* (housing infrastructure constraint), as well as the number of residents (housing infrastructure constraint). Fixed shares specify the distribution of *residents* and *tourists* between the coastal zone and the rural area.

Given the *water use per person* (considered to be similar for residents and tourists), the model calculates the total *domestic water demand* and the *coastal share for water demand*, which is proportional to the coastal share of the population. These variables are inputs to the water sub model that calculates the actual water use (taking into account the available stock) and simulates the treatment of water by WWTPs (cf. Sub model 1).

The attractiveness of the territory is represented by a theoretical index that ranges from 0 to 1. Its value depends on several social, economic and environmental factors calculated in the model.



RESIDENTS AND TOURISTS

ATTRACTIVENESS

Figure 26: Overview of the SD population sub model.

2.4.3. Application: Tackling regional, national and international challenges and achieving sustainability

2.4.3.1. Application rationale

The outcomes of COASTAL MAL4's SD modelling and the business roadmap that it helped build with local stakeholders from the Charente River basin are useful insights for tackling several regional, national and international challenges and achieving sustainability.

2.4.3.2. Results and discussion

A first outcome to highlight is that building a model in collaboration with multiple, possibly diverging, stakeholders and using it as a reference to initiate discussions among them seems fruitful to reach a consensus and build rural-coastal synergies, in line with COASTAL's objectives. In the current time where (fake) information proliferates and is difficult to grasp as a whole, having a model that summarizes the available and relevant information (scientific and local expertise) and on which everyone agrees allows establishing an objective and appeased dialogue around complex issues. Such an unbiased decision-support tool can help avoid extreme points of view and the conflictual situations to which their confrontation may lead, like the violent episodes that surround the issue of water storage around our territory of study (Le Monde avec AFP, 2022).

Another relevant outcome is that the water resource, in terms of quantity, can be managed and used sustainably, avoiding deficits. In this year 2022, France and especially the Charente basin are undergoing an early drought episode due to a lack of rainfall. This led to restrictions on using water for irrigation and domestic purposes as early as May (Préfet de la Charente-Maritime, 2022). What the model shows then is that every stakeholder (agriculture, shellfish, tourism, population, etc.) of the land sea system should make efforts in order to save water, and in particular, agricultural systems should change towards systems using less water and inputs (new CAP policy). It also shows that using less water will certainly imply trade-offs, like in the case of agriculture where less irrigation should induce lower yields. While such trade-off may be in opposition with other objectives like the aim to produce and consume more local food (Green deal policy and response to the current conflict in Ukraine), we should not look only at yields but also diets' composition. As also shown by the model, switching to agroecological farming systems that irrigate less and promote proteaginous crops, while adapting our food regimes, can help cope with the irrigation deficit that will occur anyway, whether systems and diets are adapted or not. Another model result is that irrigating less is favourable for downstream shellfish production, which needs high water streams, and thus helps the relocation of this production, meeting the objectives of consuming local products and maintaining traditional activities (Farm2Fork policy). Once again, collaboration among coastal and rural stakeholders is necessary to find consensual solutions and having a model that highlights the global trade-off induced by adapting each of their activities can help find an efficient common organisation.

A last important outcome is that transforming towards production systems that appear as more sustainable is not a synonym for economic losses, which is often a commonly used argument against sustainable development. As shown by the model, margins and employments in different activities can remain high and even increase further. In this regard, the model does not tackle the issue completely since it does not touch the question of future individual purchasing power and thus assumes, for instance, that oysters of higher quality will be bought at a higher price in the same quantity. So, the model does not question whether economic development will actually occur and under which condition. Still, it shows that opportunities to maintain economic development will exist when adapting production and consumption systems to be more sustainable. As promoted in the BRM, taking advantage of these opportunities will require a political and social coordination at the scale of the territory, based on the consultation of stakeholders and aimed towards fostering synergies among their activities.

2.5. Multi-Actor Lab 5 -Danube's Mouths and Black Sea (Romania)

2.5.1. Problem scope of the land-sea system

In addition to supporting a high level of *biodiversity*, the Danube Delta Region provides many benefits for humans (ecosystem services). It has an important effect on *water quality*, and *nutrient* retention, especially for the Black Sea ecosystems. Moreover, it provides extensive economic and environmental benefits to the entire region: the socio-economic benefits of the wetlands to local communities living in and around the Danube Delta are very important. Practically, all aspects the delta's inhabitants' lives are related to water in one way or another. Agriculture is practised, both in polders for cereal crops (wheat, barley, maize), sunflowers, and, on a smaller scale, for family needs (vegetables, fruit trees, vineyards) (Baboianu, 2016).

A dual challenge for the sustainable development of the Danube Delta is the conservation of its ecological assets and the improvement of the quality of life for its residents and to strike a balance between protecting the unique natural and cultural assets of the Danube Delta Region and meeting the aspirations of the region's inhabitants to improve their living conditions and seek better economic opportunities (World Bank, 2014a).

A general conclusion of the stakeholders' meetings outlined that governance and excessive bureaucracy are disturbing the economic activity (planning, facilities for investors (lack of), lack of compensatory measures, tourism, infrastructure) and social areas (health, incomes, protection, jobs), avoid real problems like the conflict between Marine Protected Areas (and restrictive measures) and the exploitation of resources or the Danube Delta's clogged canals and invasive species. Agriculture has clear impacts on both inland and coastal water quality and the locals are not aware of causes, effects and impacts of the pollution on the Black Sea and even on the surrounding neighbourhood. The agriculture is for subsistence and the area is very poorly developed. Due to the Danube Delta protected area, there is a pressure along the coastal zone for seasonal tourism (only three - four months/year). Thus, there is an artificial population "growth" that is not sustained by the "real" economic development.

In accordance with its Biosphere Reserve status, the Danube Delta is expected to be governed by policies converging towards an integrated economic, societal, cultural, and environmental sustainability (Petrişor et al., 2016). While past anthropic activities in the Danube Delta led to important impacts on the natural environment there are also economic activities which can be optimized to become sustainable on the long term, such as ecotourism, reed harvesting and processing and small-scale businesses based on traditional activities (Sbarcea et al., 2019).

The unique ecosystem of the North-Western Shelf of the Black Sea is burdened by excessive loads of nutrients and hazardous substances from the coastal countries and the rivers that discharge into it and where the Danube is the river with the highest discharge. Pollution inputs and other factors radically changed Black Sea ecosystems beginning around 1960. Other pressures on the Black Sea ecosystems include organic pesticides, heavy metals, incidental and operational spills from oil vessels and ports, overfishing and invasions of exotic species.

Today, the Black Sea catchment is still under pressure from excess nutrients and contaminants due to emissions from agriculture, tourism, industry, and urbanization in the Danube basin. This prevented achieving the Good Environmental Status by 2020, as required by the EU-Marine Strategy Framework Directive. The increased rates of eutrophication, pollution are important stressors for the Black Sea ecosystem (INCDM, 2018).

The goal of the model is to explore alternative scenarios to improve the quality of life and sustainability within the Danube Delta Biosphere Reserve (DDBR) and its marine waters (Black Sea) as one of the most impacted areas along the Romanian littoral. Land-sea interactions in the coastal MAL5 region were identified through separate sector workshops and a combined multi-sectoral workshop as part of WP1 in the COASTAL project. Land-sea interactions are at the core of our study case (Figure 27). For practical reasons due to data availability and considering that the activity on the area upstream has effect on this highly biodiverse area, data collected for the county of Tulcea is included in the model.

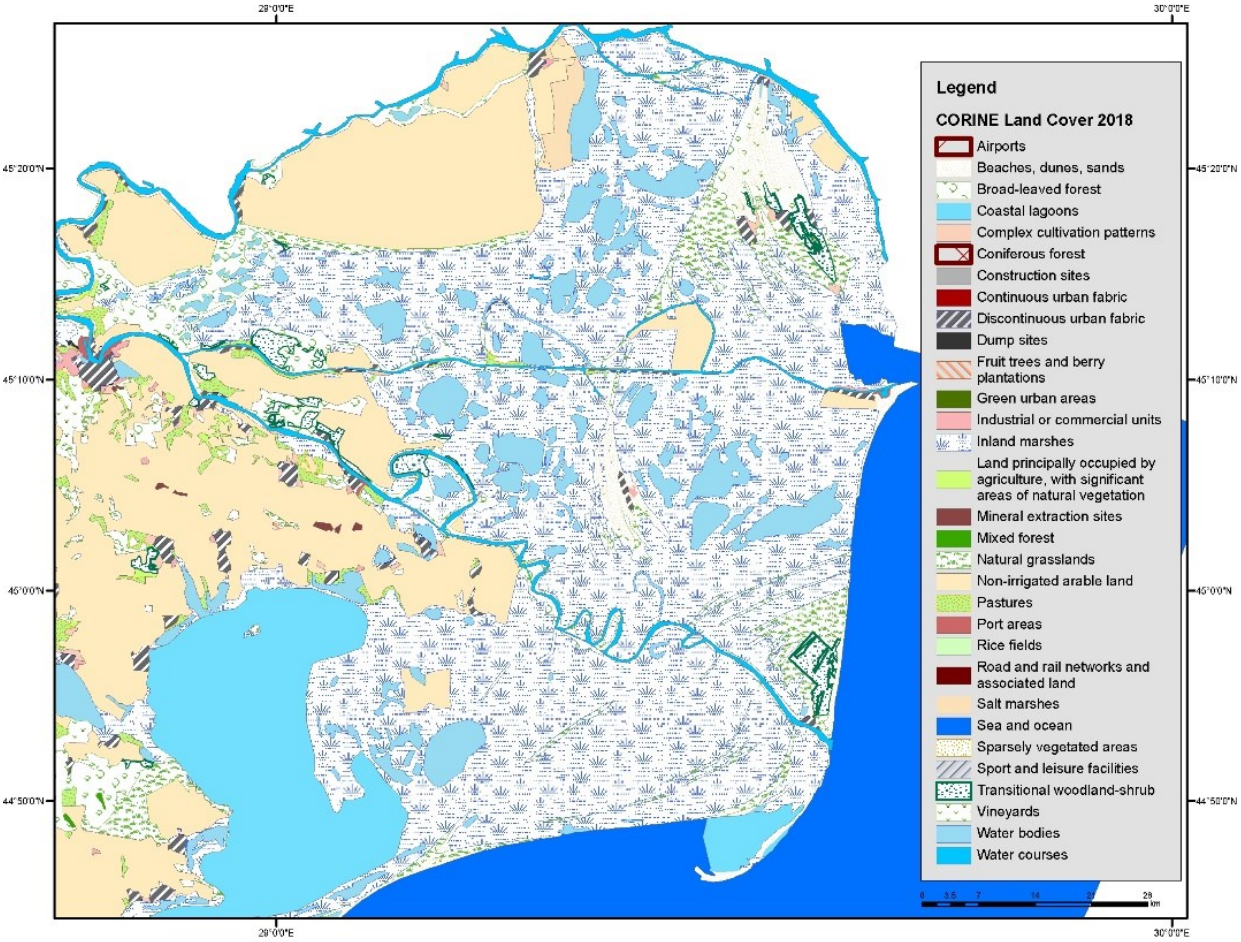


Figure 27: Map of the geographic area - Danube's Mouths – Black Sea case.

2.5.2. Description of stock-flow models

The modelling for the Romanian MAL focused on three stock-flow sub-models: one model for transition to ecological agriculture, the second for intensifying aquaculture and a third one for introducing slow tourism in the Danube Delta. The models were designed as strategic policy tools with a long-time horizon of decades to address the sustainable development of the Danube Delta. The latter is a dual challenge with on the one hand the requirement to protect its unique natural and cultural assets and other hand the need to meet the aspirations of the inhabitants to improve their living conditions and seek better economic opportunities.

The main objective of the model is to investigate how the different coastal-rural sub sectors that are considered affect each other. Where the three sub-models differ in problem scope, they are linked through the impact of the nitrogen input from each modelled sector and how the sectors influence each other and their overall impact.

2.5.2.1. Sub-model 1: Agriculture

The core objective of this sub-model is to model the transformation from conventional farming vs eco farming by trying to fulfil the EU's recent recommendations, while assuring food security and farmer's competitiveness on the market.

The conversion to eco-farming is expected to have a beneficial effect on the environment by decreasing the negative impact of farming on soil, water and air quality. With respect to the land-sea interactions, the focus of the COASTAL project, this sub model accounts for the impact of farming on water quality. The model is structured as a generic one crop system, namely wheat production. This crop was chosen as it has the largest share of the cultivated area in the case study region. Moreover, organic wheat has the highest share in organic farm production both across the entire country and in the case study area with an average of 30% and a steady increase over the last ten years. As accurate official statistics are available at the county level , we took into account, as a case study region, the entire county of Tulcea. The start and end times of the model were set to 2019 and 2050 respectively.

The model has two stocks: *traditional farms area* and *eco farms area*. The entire architecture has a symmetric structure for several variables (*farm income, farm production, fertiliser used*): one set for the traditional farming system and one for the eco farming system.

The *eco farms area* equation was set taking into account the Farm2Fork strategy of at least 25% of European agricultural area to be cultivated under organic system by 2030. At present, the organic production area in Romania accounts for 2,9% of total agricultural land. Tulcea county is ranking first in the country with 16% of the total agricultural land of the county area under ecological farming.

Figure 28: Agriculture SD model

The overall traditional farm income is calculated based on production value (total traditional farms production multiplied by crop price) divided by traditional farm area and subtracting the traditional farm production cost. The same rationale was used for eco-farm income. The traditional farm yield is expressed as tons crop per year and is obtained by multiplying the average farm production and the total area under traditional farming system. Again, the same rationale applies for eco-farm yield. The higher the yield is the higher the productivity and profitability of a farm and this increases the well-being of farmers. Generally improved yields are generated with improved practices (innovation, farming infrastructure, irrigation, crop varieties). As our objective is to study land sea synergies, we have chosen to model the water needs, fertiliser use and, at the stakeholder's suggestion, the installation of forest belts as a mitigating measure. Regarding the fertilisers, the variables implying this production factor should be read as Nitrogen containing fertilisers. This decision was taken to address the most relevant compound for water quality in the area. Data on fertiliser use were extracted from official statistics and good agricultural practices code for traditional farming and farmers survey and good agricultural practices code for eco-farming.

2.5.2.2. Sub-model 2: Fish farming

In the process of the sub model development, the freshwater aquaculture stock was considered as the fish farming area (ha), which has two components – normal and intensive aquaculture stocks. The normal fish farming area is influenced by the development rate, which is a function of the spatial pressure. The normal fish farming area is decreased by the aquaculture intensification and has an impact on the normal aquaculture production, normal fish farm employment, total nitrogen load from aquaculture and total area in use for aquaculture. In turn, aquaculture intensification is the main input for the intensive fish farming area, together with its rate of development. Both stocks have an are used to calculate the total aquaculture production as a sum of fish production from normal and intensive aquaculture.

The fishery is the main traditional activity for the Danube Delta’s inhabitants and represents over 15% of the total workforce. The area has the most important aquaculture resources in Romania consisting in 2020 of 73 units covering more than 69 000 ha (nurseries and fish farms) with annual revenues of approx. 4 million Euro and 350 employees. In the model, the aquaculture intensification rate represents the yearly fraction of existing normal aquaculture area, which is changed into intensive aquaculture. The value is to be set according to different scenarios. The sub-model outputs the number of employees as a result of increasing the intensive area and the intensity of the fish farming labour.

Another important output of the sub-model is the environmental pressure from the sector which is expressed as the impact of the nitrogen load on the water quality. This impact, the water footprint, is calculated as the total nitrogen load from normal and intensive aquaculture divided by the product of maximum worst case of the nitrogen load (MAC-maximum allowable concentration from the national legislation) and the flow of the Danube’s arm.

The fishermen welfare was mentioned many times in the stakeholders meeting, and it is one of the most important targets of the Danube Delta’s strategy. In our model, it is equated to the intensive fish farming revenues and calculated from the difference between income and costs.

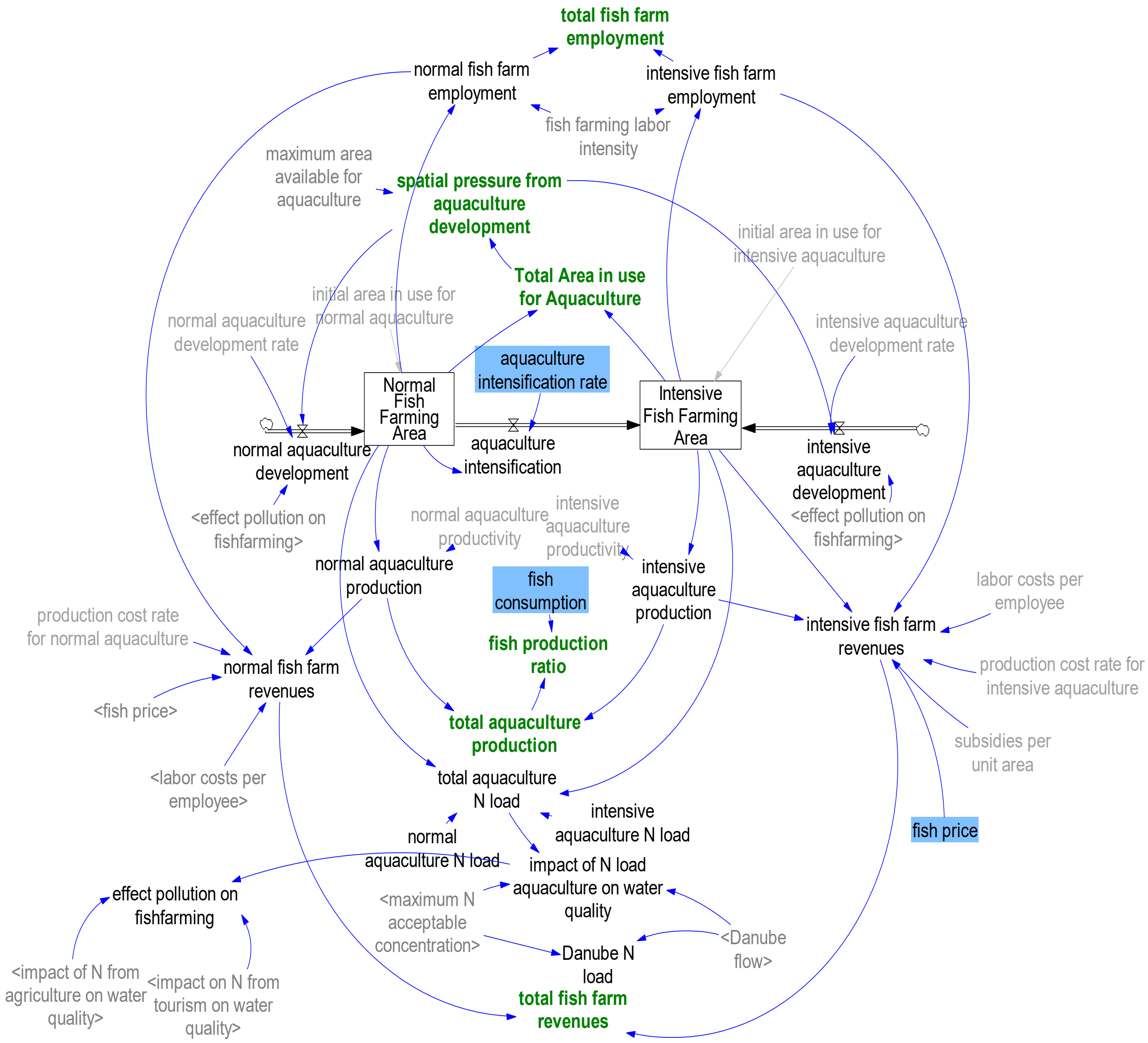


Figure 29: Operational model for the Freshwater Aquaculture

2.5.2.3. Sub-model 3: Tourism

The tourism model (Figure 30) is as the agriculture sub-model based on representative data for the Tulcea County area as this is an administrative territorial unit for which accurate data were available as input for the below model. The model includes a single stock variable, Number of Tourists, determined over a period of 30 years, taking the year 2020 as the beginning of the simulation and ending of the simulation by the year 2050. We included in the model specific quantitative input variables, such as tourism carrying capacity, employment factor, emergency level, time until emergency level is reached, revenues per tourist day, fraction of revenues used for marketing, initial number of tourists, initial duration of stay, decline rate without development, decline rate without development These variables are determined as constant variables, based on calculations made with data from National Institute of Statistics, in most cases, but also based on others scientific publications of interest for our Tourism model. Secondly, the model includes auxiliary variables: initial tourist days, Annual Tourist Days, tourism employment. In addition, the model relies on look-up functions: tourism pressure, tourism attractiveness, impact of marketing on development. For these look-up functions the shape was set together with experts and stakeholders in the field of tourism.

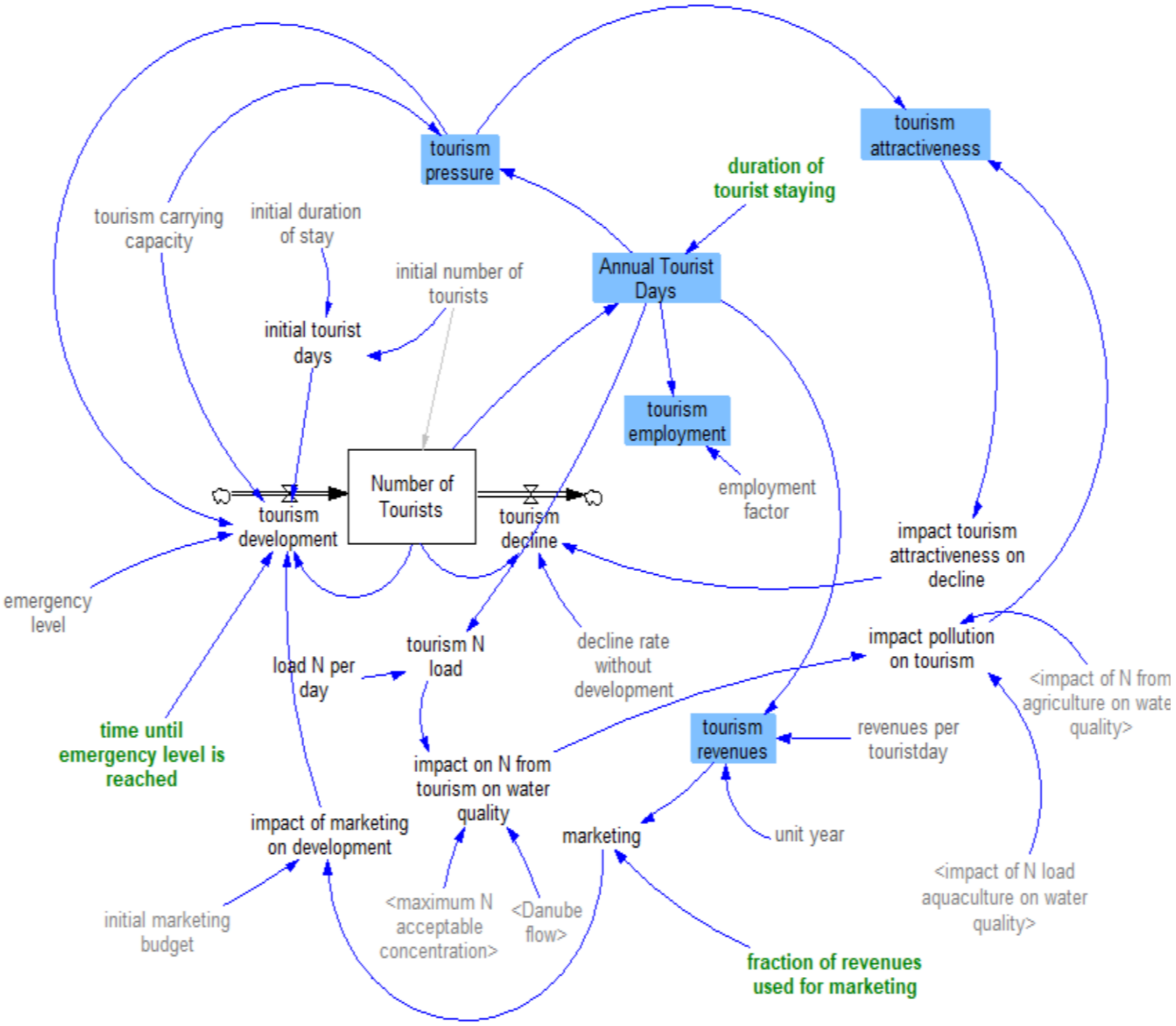


Figure 30: Stock-flow structure of SD sub model MAL5 development in VENSIM (Tourism Development)

2.5.3. Application: Supporting integrated sectoral development with science-based management decisions.

2.5.3.1. Application rationale

The Danube Delta represents both the largest remaining natural wetland and the second largest river delta in Europe, being one of Europe's most valuable habitats for wetland wildlife with 16 strictly protected areas. Unfortunately, according to our stakeholders, the governance and excessive bureaucracy are disturbing the economic activity and social areas while avoiding real problems like the conflict between Marine Protected Areas (and restrictive measures) and the exploitation of resources or the Danube Delta’s clogged canals and invasive species. Agriculture has clear impacts on both inland and coastal water quality and the locals are not aware of the causes, effects, and impacts of the pollution on the Black Sea and even on the surrounding neighborhood. The agriculture is for subsistence and the area is very poorly developed. On the contrary, due to the Danube Delta protected area, there is an increased pressure downward in the coastal zone for seasonal tourism (only three-four months/year). Thus, there is an artificial population “growth” which is not sustained by the “real” economic development. Each activity has its national strategy to which the development strategy of the Danube Delta itself. The integration of the impacts that the development of the activity has can be achieved through the COASTAL model. Consequently, in the context of COASTAL, researchers, actors and stakeholders detected the need to develop a systemic planning tool to support the integrated sectoral development with science-based management decisions.

2.5.3.2. Results and discussion

In the agriculture model, we can observe how the conversion rate from traditional farms to organic farms that is set depending on the Farm to fork strategy, affects the water quality. The model for agriculture is designed for specific field crops, but it can also be adapted to other crops, depending on the needs of the beneficiary. Eco-farming practices will reduce the nitrogen input to the water and with time the impact of pollution is reduced. The tourism model considers that the increase in tourism results in increased pollution which leads to biodiversity loss. Once the biodiversity has degraded, the area is less attractive for tourism. We observed in the tourism model, as in fish farming model or in eco farming model, that with time, the impact of pollution is reduced. Finally, the integrated model was designed to examine the cumulative impacts of individual sectoral development in different socio-economic and climate change scenarios and environment management interventions. The model results and scenarios run will be presented as an innovative tool to the national and local authorities on ICZM Strategy and will be the basis of the Design and setup Training Courses for the Operational Program Administrative Capacity POCA/399/1/1: Improving the capacity of the central public authority (Ministry of Environment & Waters) in the field of Integrated Coastal Zone Management (ICZM). One of the main added values of the tool is that it covers a science-policy niche and can help the debate on the long-term impacts of integrated sectoral activities development and give support for decisions making process in various national and international environments, such as ministerial thematic groups, European initiatives and strategic plans design.

2.6. Multi-Actor Lab 6 - Mar Menor Coastal Lagoon (Spain)

2.6.1. Problem scope of the land-sea system

The Mar Menor coastal lagoon (135 km^2) is located in the Region of Murcia (SE Spain). The catchment draining into the Mar Menor covers an area of 1.255 km2 and is mainly covered by intensive irrigated agriculture with horticulture, tree crops and greenhouses, while the coastline is occupied by villages and tourist accommodations (Figure 31). The area is characterized by multiple environmental, social-cultural and economic interests, often competing for scarce resources, water being the most important. There is a high potential for complementarity, win-win scenarios, development of sustainable business cases based on public-private collaboration, efficient use of water, innovative farming practices and a transition to sustainable models of tourism and agriculture.

Figure 31: Cropland area in the Campo de Cartagena near the Mar Menor lagoon (Author: Javier Jiménez).

The intensive and highly profitable irrigated agriculture mainly depends on scarce low-quality groundwater and water from inland inter-basin water transfers. Agriculture provides labour and income to the region but forms a source of excessive nutrients, sediments and other forms of contamination into the Mar Menor coastal lagoon. The resulting poor water quality affects the ecology of the lagoon with severe implications for its potential function for tourism and fisheries. The coastal lagoon forms part of a Specially Protected Area of Mediterranean Importance (SPAMI).

The Mar Menor is one of the hotspots for tourism in the Region of Murcia, with a total number of 346,000 tourists and 1.4 million overnight stays in 2016. Beside international visitors, the Mar Menor has an important touristic function for the regional population (1.5 million inhabitants). The availability of water for irrigation and drinking water for tourism will be further reduced under future climate conditions. As such, the Mar Menor is strongly influenced by interactions between inland agriculture on the one side, and coastal tourism, salt pans and fisheries affecting natural ecological values and socioeconomic sustainability on the other side.

The need to move towards sustainable modes of agriculture and tourism is increasingly recognized and recently revived strongly due to a sudden increase in contamination levels resulting in a strong drop in tourism. The main driver that has caused a hydrological and nutrient imbalance in the study area is intensive agriculture, and to a lesser extent due to insufficient urban wastewater treatment and historic mining activities in the area. The opening of the Tajo-Segura water transfer in the 80’s promoted an uncontrolled flourishing of irrigated croplands in an area that had been traditionally dominated by rainfed agriculture. Public administration has not been very successful in controlling the implementation of best agricultural practices, and there is a general lack of support for touristic activities by the local and regional governments. This favours the uncontrolled development of agriculture and tourism expansion leading to the ecological collapse of the Mar Menor lagoon. This crash is negatively affecting the attractiveness and touristic potential of the area and impoverishing local communities.

The identification of most effective solutions and possible trade-offs requires careful assessment of system interactions and feedback mechanisms, which is the focus of the system dynamics model. Following the outcomes of the sectoral and multi sector stakeholder workshops, the main processes that the SD model for Mar Menor and its catchment area considers and will affect land-sea interactions are:

2.6.2. Description of stock-flow models

Figure 32 shows an overview of the system dynamic model developed in MAL6, highlighting the relationships among the different topics modelled and between coastal and rural aspects. All three economic sectors (agriculture, tourism, photovoltaic renewable energy) contribute to the total economic profit and jobs in the study area. The Mar Menor ecological status is influenced by the agricultural development via water and nutrients input and the implementation of SLM practices and nature-based solutions. On the other hand, the ecological status of the lagoon affects coastal and rural tourism development and social awareness and governance, which in turn could lead to the adoption of SLM practices and regulate the development of the agricultural sector. Besides, there is a potential synergy between the agricultural and the tourist sectors via promoting agrotourism activities.

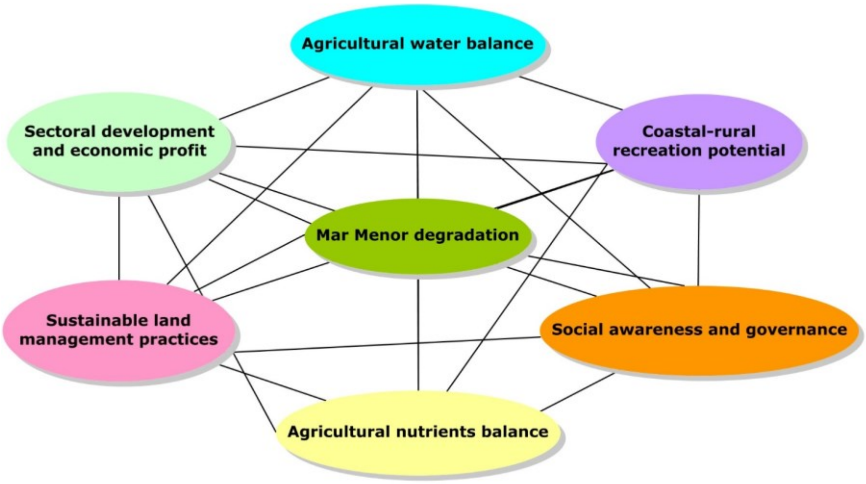


Figure 32: Overview of the sub models of the MAL6 system dynamic model representing land sea interactions.

Figure 33 shows the main feedback loops contained in the model structure. The Mar Menor degradation, mainly caused by agricultural nutrient inputs and indirectly affecting tourist growth via coastal recreation potential, also affects social pressure on public administrations, which in turn negatively affects agricultural development. Besides, the expansion of irrigated land areas increases water demand and agricultural pressures on water resources, which in turn decreases the potential growth of agriculture based on water availability. Furthermore, the increase in agricultural water demand also increases the groundwater needed, thereby producing brine wastes and more nutrients inputs to the lagoon. The social pressure on public administrations and the implications for agricultural and tourism growth potential are central in the effectiveness of this feedback loop.

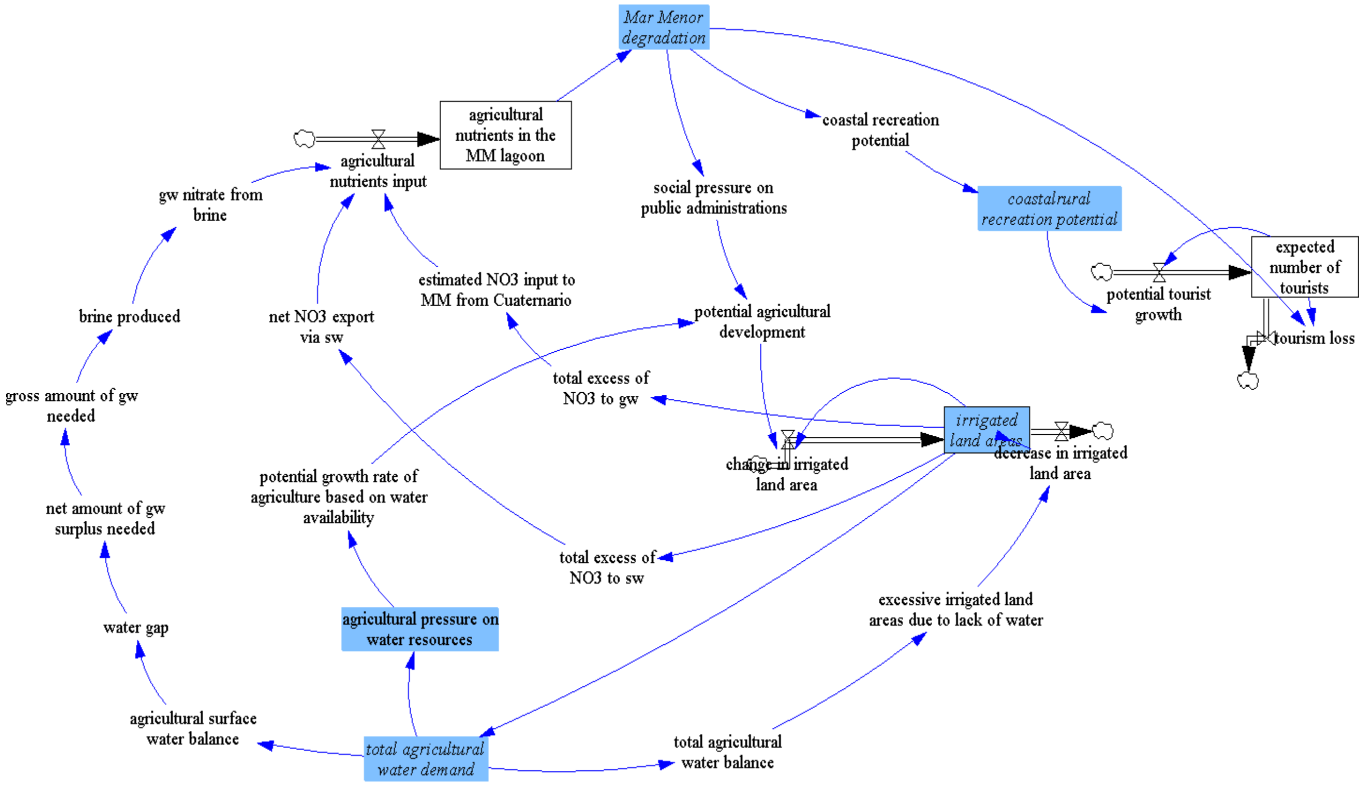


Figure 33: Main feedback loops of the MAL6 pilot system dynamic model.

2.6.2.1. Sub model 1: Agricultural water balance

In the stock-flow model of the agricultural water balance (Figure 34), we included all variables that determine water demand from agriculture and water supply from all different sources. Groundwater extraction is calculated based on water deficit. 'ATS opened' is a binary variable that becomes 1 in 1979 when Tagus-Segura (TS) water transfer was opened. The available water from TS water transfer for the Campo de Cartagena is obtained by multiplying the average total TS water transfer (330 hm3/year; Morote et al., 2017) by the fixed share of ATS water for the 'Comunidad de Regantes del Campo de Cartagena' (CRCC) of 15% (TRAGSATEC, 2019). Available water from Tagus river is constant for the historical period covered by the model in the Business as Usual scenario (BAU) but can be changed to create future scenarios of climate change based on existing literature that gives estimates for the RCP4.5 (123.3 hm3/year; Pellicer-Martínez and Martínez-Paz, 2018) and RCP8.5 (86.2 hm3/year; Pellicer-Martínez and Martínez-Paz, 2018) projections and how these change the water availability for transfer between Tajo and Segura catchments. A scenario of gradually stopping the TS water transfer until 2070 is also considered.

The available surface water for agriculture is the sum of: (1) the available water from TS water transfer, (2) other catchment water sources (11 hm3/year; TRAGSATEC, 2019), (3) the sea water desalination (by default 8.2 hm3/year; TRAGSATEC, 2019), (4) urban wastewater treatment plant effluents (29.8 hm3/year; TRAGSATEC, 2019) and eventually (5) the additional water extracted from the aquifer if the Vertido Cero (VC) Plan starts (annual water pumped by the VC). The 'VC plan' (VCOnOff) might be eventually launched by the National government and aims to extract polluted water from the aquifer, clean it from salt and nitrogen, and give it back to farmers for irrigation at an agreed price. In the sub model, when this scenario is activated, the amount of surface water available for agriculture is increased by the expected Annual water pumped by the VC (12 hm3/year; TRAGSATEC, 2019). The sea water desalination is a function of the yearly average of sea water desalination and the change in sea water desalination amount (a variable that can be changed from -1 to any positive value with zero meaning no change).

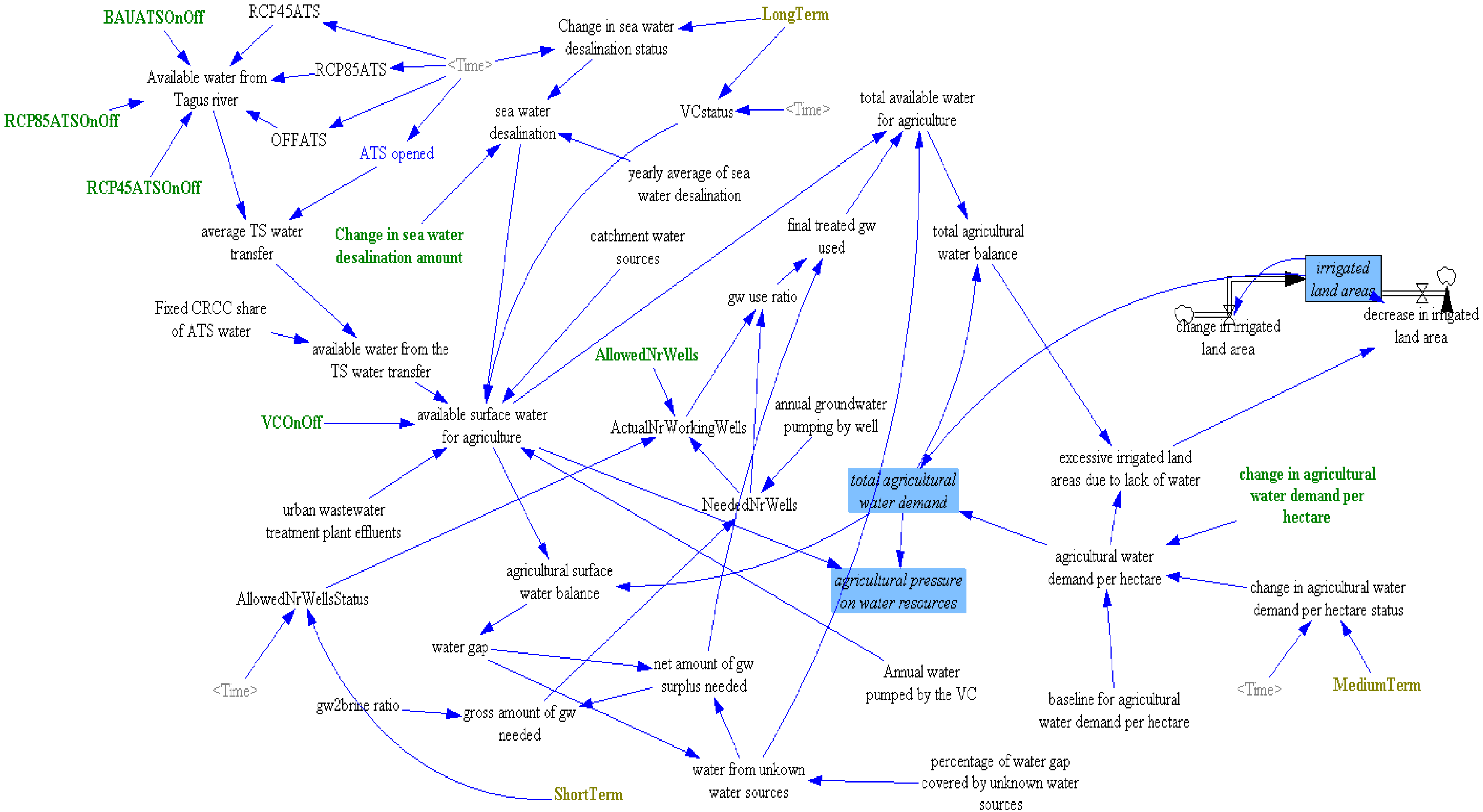


Figure 34: stock-flow model structure for the agricultural water balance sector. Green colour variables represent main scenarios. Variables with blue background represent key performance indicators.

The total agricultural water demand is calculated by multiplying the agricultural water demand per hectare by the irrigated land area. The agricultural water demand per hectare is a function of the baseline for agricultural water demand per hectare (0.004 hm3/ha; TRAGSATEC, 2019) and the change in agricultural water demand per hectare, which can be modified based on climate change assumptions or the implementation of less water demanding crops. The agricultural surface water balance is computed by subtracting the total agricultural water demand from the available surface water for agriculture. The water gap (in hm3) is zero if the agricultural surface water balance is positive and otherwise it corresponds to its absolute value. The net amount of groundwater (gw) surplus needed is a function of the water gap minus the water from unknown water sources. The latter variable is a function of the water gap multiplied by the percentage of water gap covered by unknown water sources (30%; Personal communication during expert interviews). The gross amount of gw needed is then computed by multiplying the net amount of gw surplus needed by 2 minus the gw2brine ratio (75% of water in groundwater excluding salt and nutrients; TRAGSATEC, 2019), in order to account for the extra water needed when considering the amount of brine present in the groundwater. The gross amount of gw needed it then used to calculate the NeededNrWells by dividing it by the annual groundwater pumping by well - the model considers an average value by wells of 0.19 hm3 per year (TRAGSATEC, 2019). The ActualNrWorkingWells corresponds to the NeededNrWells unless this is higher than the AllowedNrWells, which is then the final maximum value assigned. AllowedNrWells acts here as a scenario in which the number of allowed wells (or the corresponding allowed water pumped) can be established by regulations (by default the value is considered unlimited in the model). The gw use ratio is computed by dividing the ActualNrWorkingWells by the NeededNrWells.

Total available water for agriculture is the sum of the available surface water for agriculture, the final treated groundwater produced, and the water from unknown water sources. The final treated groundwater used is a function of the net amount of groundwater surplus needed and the groundwater use ratio. The total agricultural water balance is computed as the total available water for agriculture minus the total agricultural water demand. The agricultural pressure on water resources is a function of the available surface water for agriculture and the total agricultural water demand. It is zero if the available surface water for agriculture is higher than the total agricultural water demand and otherwise equals to the total agricultural water demand minus the available surface water for agriculture, divided by the total agricultural water demand.

The decrease in irrigated land area is a function of the excessive irrigated land areas due to lack of water and the amount of irrigated land areas. The excessive irrigated land areas due to lack of water is a function of the total agricultural water balance and the agricultural water demand per hectare.

All variables in the model that are named “status” for this or any other sub model represent binary variables that are turned on when the specific time period to which they are linked starts. These periods (LongTerm: 2030, MediumTerm: 2026 and ShortTerm: 2022) are linked to different solutions according to the timing proposed by stakeholders.

2.6.2.2. Agricultural nutrients balance

There are three main sources of agricultural nutrient inputs to the Mar Menor lagoon (Figure 35), i.e., nutrients contained in (1) surface water (sw) runoff (net NO3 export via sw), (2) in groundwater (estimated NO3 input to MM from Quaternary aquifer) and (3) in brine wastes (gw nitrate from brine - resulting from polluted water being pumped from the aquifer and then treated to remove excessive salts and nutrients). This sub model is primarily driven by the excessive use of fertilizers per hectare (average excess of fertilizer use) and by agricultural expansion (hectares of irrigated land areas).

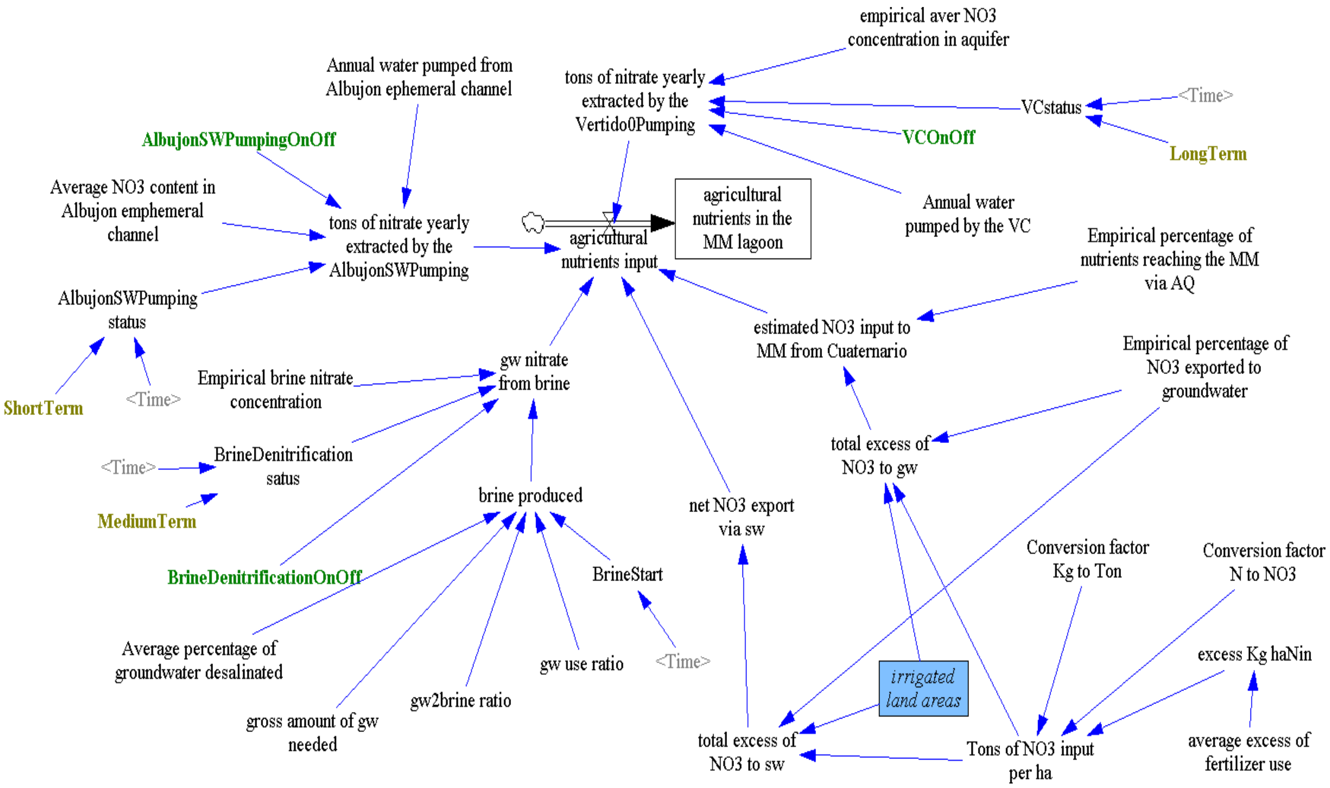


Figure 35: stock-flow model structure for the agricultural nutrients balance sector. Green colour variables represent main solution scenarios. Variables with blue background represent key performance indicators.

The average excess of fertilizer use refers to Kg/ha of Nitrogen that is not taken up by the crops (40 Kg/ha; TRAGSATEC, 2019), which is then converted into tons of nitrate (NO3) per hectare. The total excess of NO3 to gw and *sw* are calculated as a function of the tons of NO3 input per ha, the number of irrigated areas and the empirical percentage of NO3 exported to ground- and surface-water, estimated as 85% and 15% respectively (TRAGSATEC, 2019). The water and nutrient fluxes in the soil and aquifers are highly complex processes that would require a different dynamic modelling approach and significant additional field data collection. Therefore, we established an empirical percentage of nutrients reaching the MM via the aquifer (AQ) of 18% based on most recent literature data reporting on measured fluxes from the aquifer to the MM (TRAGSATEC, 2019). This percentage is then multiplied by the total excess of NO3 to gw and gives the estimated NO3 input to MM from the Quaternary aquifer. For the surface water nutrients export, another variable is included, the net NO3 export via sw, as a function of the total excess of NO3 to sw reduced by the effect of sustainable land management practices that could be implemented as a scenario. This scenario is however not indicated in this sub model but explained in the section corresponding to sub model 7.

Since the aquifer is polluted with nutrients, when groundwater is pumped to be used for irrigation around 50% of it is filtered to exclude salts and nutrients (average percentage of groundwater desalinated) starting in 1995 (BrineStart personal communication during expert interviews), thereby producing brine, which is discarded by farmers and in the absence of an operational recollection or denitrification system, drained to the lagoon. The variable 'gw nitrate from brine' corresponds to the tons of nitrate produced and exported to the lagoon and is calculated as a function of the brine produced, the empirical brine nitrate concentration (199.35 tons/hm3; Álvarez-Rogel et al., 2020) and the BrineDenitrificationOnOff scenario. The effect of a brine denitrification technology being currently developed is therefore included in the model as a scenario (BrineDenitrificationOnOff) that would avoid the export of these brine wastes to the lagoon. The brine produced is calculated as a function of the average percentage of groundwater desalinated, the gross amount of gw needed, the gw use ratio and the gw2brine ratio (explained in sub model 1).

The Vertido Cero Plan (VCOnOff), as explained in the previous section, is based on extracting water from the aquifer in order to reuse the water, once denitrified, and is also expected to decrease the nutrient inputs from the aquifer to the lagoon directly (via groundwater flux) or indirectly (via superficial base flow coming from the aquifer). The 'tons of nitrate yearly extracted by the Vertido0Pumping' refer to the amount of nutrients that would not reach the Mar Menor once the infrastructure would start working based on the annual water pumped by the VC (see sub model 1) and the empirical average NO3 concentration measured in the aquifer (180 t/hm3; TRAGSATEC, 2019). The surface water pumping from the Albujón ephemeral river (AlbujonSWPumpingOnOff) is considered in the model as another of the planned initiatives. The tons of nitrate yearly extracted by the AlbujonSWPumping are computed as a function of the annual water pumped from Albujón ephemeral channel (2 hm3; CHS, 2019) and the average NO3 content in Albujón ephemeral channel (175 tons/hm3; TRAGSATEC, 2019).

Agricultural nutrients input to the lagoon is finally computed as the sum of the estimated NO3 input to MM from Quaternary aquifer, the gw nitrate from brine, and the net NO3 export via sw minus the tons of nitrate yearly extracted by the Vertido0Pumping and the tons of nitrate yearly extracted by the AlbujonSWPumping. The nutrients in the MM lagoon are then accumulated and will be related to the degradation status of the lagoon, as explained in the section corresponding to sub model 4.

2.6.2.3. Sub model 3: Sectorial development and economic profit

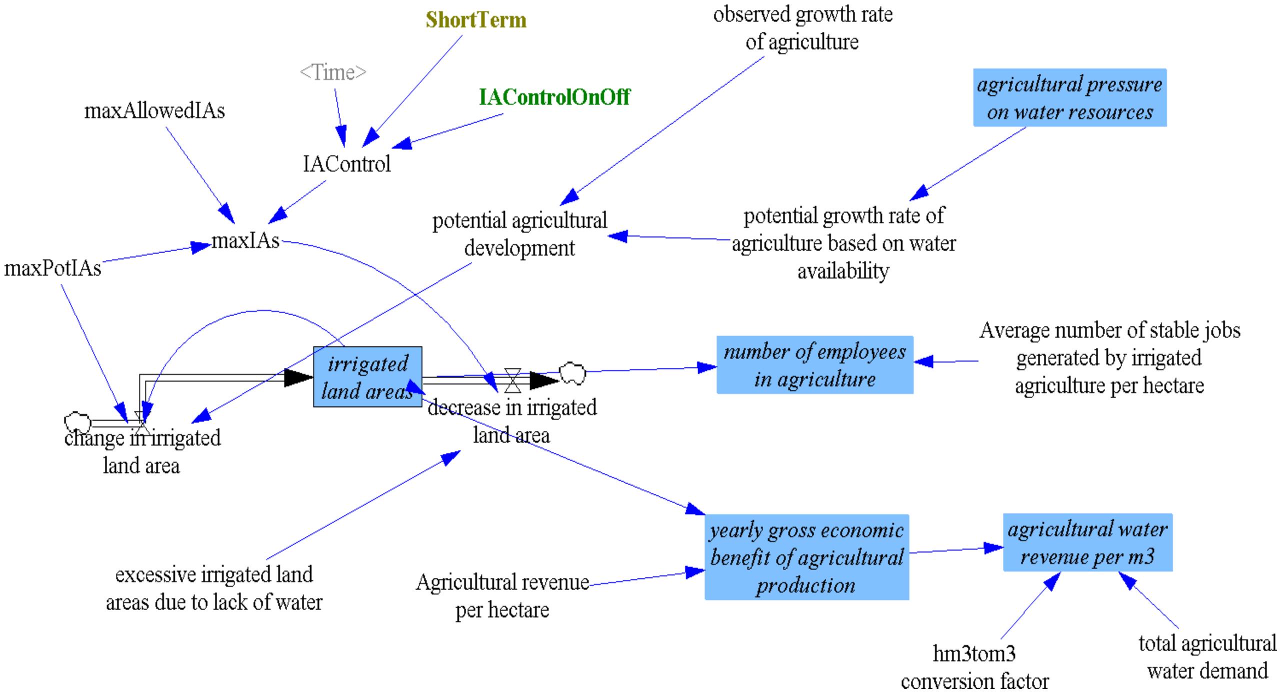


Figure 36: Stock-flow model structure related to agricultural development. Variables with blue background represent relevant indicators.

In relation to agricultural development (Figure 36), the change in irrigated land area is a function of the existing irrigated land areas and the potential agricultural development, which is driven by the potential growth rate of agriculture based on water availability (a function of the agricultural pressure on water resources and the observed growth rate of agriculture based on its historical observed growth rate (7%; Carreño et al., 2015)). The agricultural pressure on water resources does not account for groundwater that could be used to decrease the water scarcity because the main driver of the agricultural expansion is indeed the Tagus-Segura water transfer. Groundwater has been historically very limited and its current availability is only due to the high recharge rates by irrigation effluents. The model imposes a limit of 90,000 hectares to the irrigated land areas (maxPotIAs) based on spatial constraints of the geographical area (CARM, 2017). Besides, the model can further limit the amount of irrigated land areas (IAControlOnOff) down to the current area with legal access to water sources (maxAllowedIAs = 41,562 ha; CARM, 2017). The number of irrigated land areas is a function of the change in irrigated land area and the decrease in irrigated land area, with an initial value of 4,366 has in 1964 (López Ortiz, 1999). The decrease in irrigated land area is a function of an eventual policy-imposed limitation in irrigated areas, previously mentioned, and an excess in irrigated land areas due to lack of water (see sub model 1).

The number of employees in agriculture is based on the extent of irrigated land areas and the average number of stable jobs generated by irrigated agriculture per hectare (0.5 employees per hectare; CHS, 2015). On the other hand, the yearly gross economic benefit of the irrigated agricultural production is a function of the agricultural gross revenue per hectare (7,885 EUR/ha; CHS, 2020) and the extent of irrigated land areas. An agricultural water revenue per m3 is also calculated as a function of the yearly gross economic benefit of agricultural production and the total agricultural water demand.

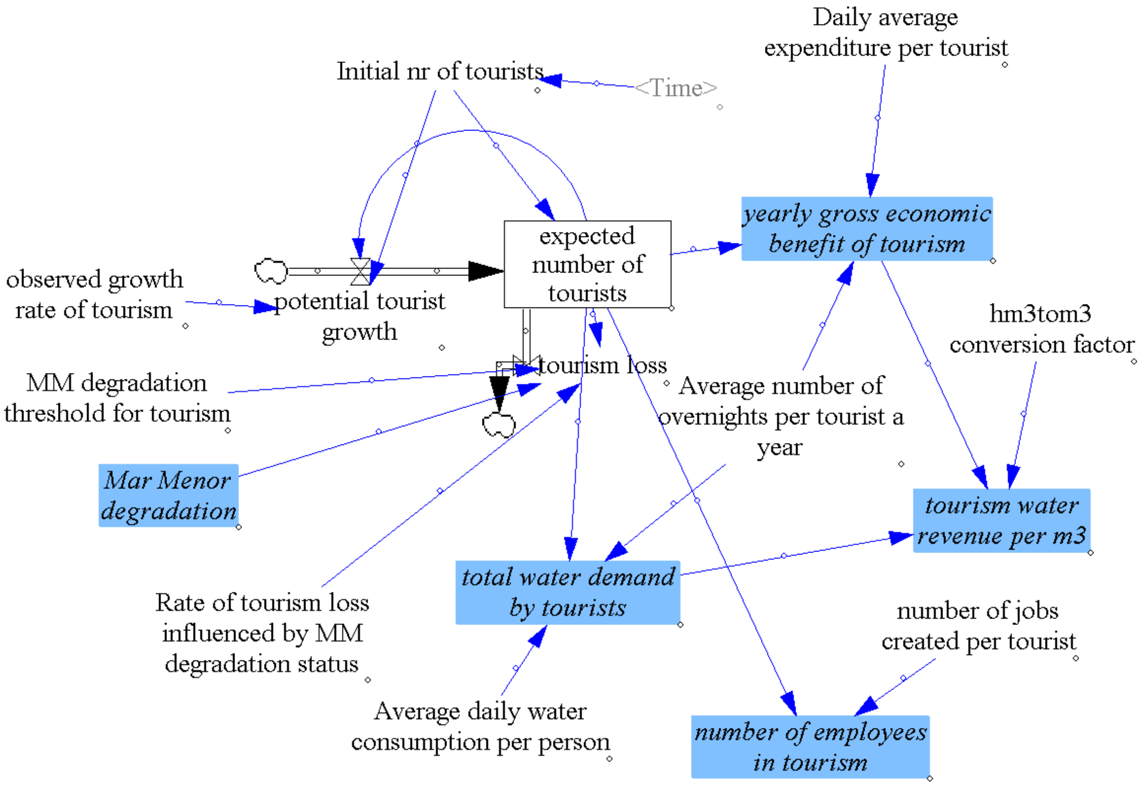


Figure 37: Stock-flow model structure related to tourism development.

In relation to tourism development (Figure 37), the yearly gross economic benefit of tourism depends on the expected number of tourists, the daily average expenditure per tourist (57 EUR/tourist*day; Arroyo Mompeán and Vegas Juez, 2019), and the average number of overnights per tourist per year (9.7 days/year; Arroyo Mompeán, 2018). The expected number of tourists increases as a function of the initial number of tourists (2 million in 1999; ECONET, 2020a) and the potential tourist growth and decreases based on the tourism loss. The potential tourist growth depends on the observed growth rate of tourism over the past years (3% per year in 2000-2019; ECONET, 2020a), the initial number of tourists and the current expected number of tourists. The tourism loss is a function of the expected number of tourists, the Mar Menor degradation, the Mar Menor degradation threshold for tourism (0.95 Dmnl; ECONET, 2020a), and the rate of tourism loss influenced by MM degradation status (1.5% per year; ECONET, 2020a). The number of employees in tourism is calculated based on the expected number of tourists and the number of jobs created per tourist (1 job every 85 tourists; ECONET, 2020a). The model also calculates the tourism water revenue per m^3, which is a function of the yearly gross economic benefit of tourism and the total water demand by tourists. The total water demand by tourists is calculated based on the Average daily water consumption per person (2×10^{-7} hm^3/tourist; Ayuntamiento de Torre Pacheco, 2019), the expected number of tourists, and the average number of overnights per tourist a year.

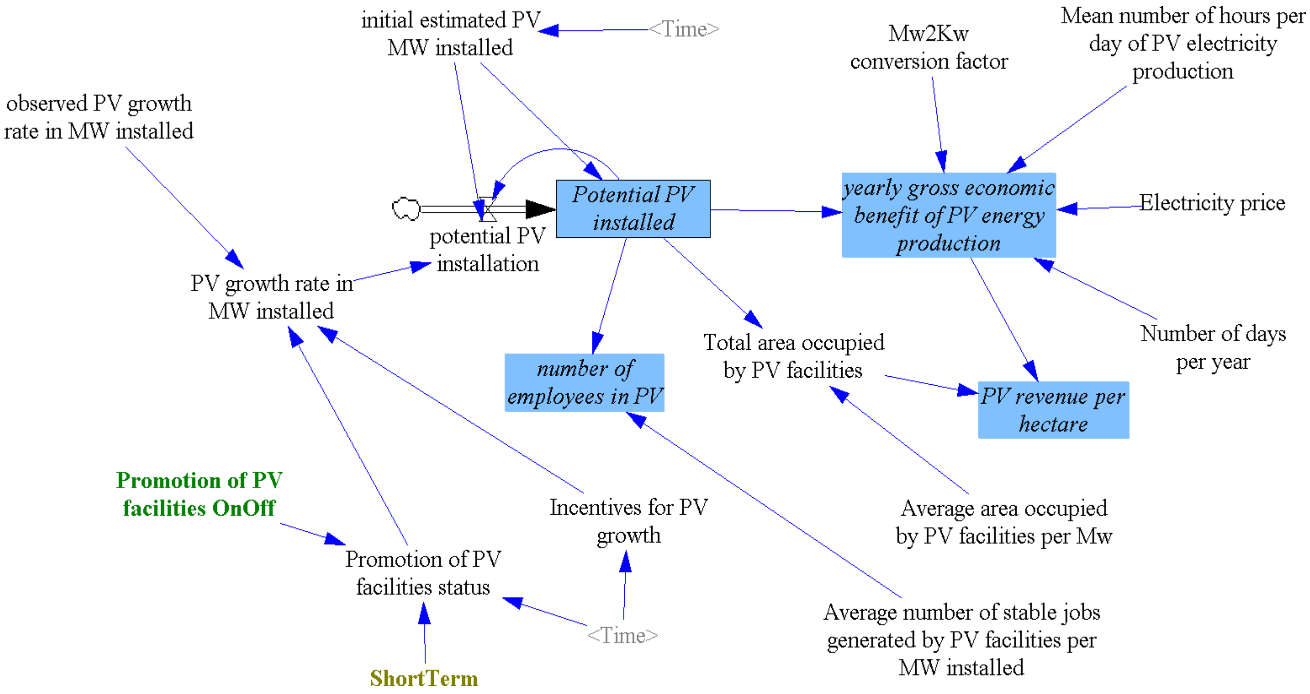


Figure 38: Stock-flow model structure related to renewable energy development.

In relation to the development of photovoltaic energy facilities (Figure 38), the potential PV installed refers to the total power capacity of solar photovoltaic energy installed measured in Megawatts and it is a function of the initial estimated PV MW installed in the Campo de Cartagena (224 Mw in 2019; ECONET, 2020b) and the potential PV installation. The potential PV installation depends on the initial estimated PV MW installed, the potential PV installed, and the PV growth rate in MW installed, which depends on the observed PV growth rate in MW installed (1.6% per year; ECONET, 2020b), the incentives for PV growth (additional growth of 5.4% per year starting in 2021 and ending in 2050; APPA, 2018), and the promotion of PV facilities status, which is activated by a scenario (Promotion of PV facilities OnOff) at a specific time (ShortTerm). The number of employees in PV depends on the potential PV installed and the average number of stable jobs generated by PV facilities per MW installed (3 jobs/Mw; APPA, 2018). The yearly gross economic benefit of PV energy production is a function of the potential PV installed, the electricity price (0.05 EUR/Kw*hour; APPA, 2018), the average number of hours per day of PV electricity production (5 hours/day; APPA, 2018) and the number of days per year (365 days). The model computes the PV gross revenue per hectare based on the yearly gross economic benefit of PV energy production and the total area occupied by PV facilities, which is a function of the potential PV installed and the average area occupied by PV facilities per Mw (2 ha/Mw; personal communication expert interviews).

2.6.2.4. Sub model 4: Mar Menor degradation

One of the main challenges was to quantify degradation of the Mar Menor lagoon over time (*Figure 39*) since it went through a rapid and recurrent ecological collapse starting in 2016. The amount and complexity of ecological processes occurring at different scales and realms within the lagoon made it impractical to develop an accurate model of ecological processes within the lagoon. Therefore, we had to simplify the model equations and calibrate the model outputs based on observed patterns and identify the most important causes and drivers.

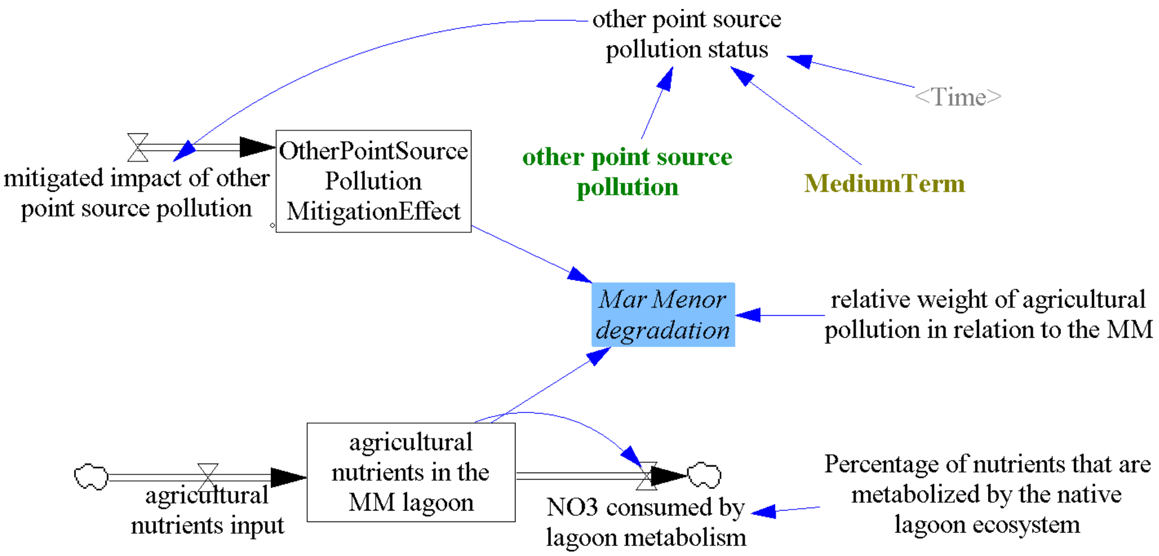


Figure 39: Stock-flow model structure for the Mar Menor degradation sector.

The Mar Menor degradation is a function of the input from agricultural nutrients and other point-sources towards the MM lagoon. Other point-source pollution sources are measured in relative terms, from 0 to 1 and are assumed to be constant with a value of 1 at least until 2026 (MediumTerm), when a scenario of pollution reduction can be activated. This reduction in point-source pollution would increase the mitigated impact (1 - other point source pollution status), which would slowly increase the mitigation effect that is zero by default (when other point source pollution is equal to one). Based on stakeholders and expert opinion, the model considers that the maximum amount of point source pollution is the historical and current one and does not account for a potential increase in point source pollution.

The contribution of agricultural pollution sources in the Mar Menor degradation is reflected in a relative weight of agricultural pollution in relation to the MM (versus other point source pollution) of 85% (Guaita-García et al., 2020). The agricultural nutrients in the Mar Menor lagoon are accumulated over time and are calculated as the difference between the agricultural nutrients input (explained in the section corresponding to sub model 2) and the NO_3 consumed by lagoon metabolism, which is a function of the agricultural nutrients in the Mar Menor lagoon and the percentage of nutrients that are metabolized by the native lagoon ecosystem (20% of the total nutrients accumulated; Comité de Asesoramiento Científico del Mar Menor, 2017). The Mar Menor degradation goes from 0 to 1, from undegraded to degraded status and is calculated using an exponential function to match the observed degradation status over time.

2.6.2.5. *Sub model 5: Coastal-rural recreation potential*

The potential tourism growth variable (Figure 40), primarily depending on the observed growth of tourism, as explained in sub model 3, also accounts for the coastal-rural recreation potential, which is the average of the coastal and rural recreation potential. The rural and coastal ecotourism activities variables represent scenarios, going from 0 to 1 and defaulting in 0, that reflect the increase in the number of rural and coastal ecotourism activities. Both scenario variables affect the impact of coastal or rural ecotourism, which is then slowly increasing the coastal or rural ecotourism effect (CoastalEcoEffect and RuralEcoEffect), ultimately affecting the coastal or rural recreation potential. The coastal recreation potential is a function of the CoastalEcoEffect and the Mar Menor degradation, whereas the rural recreation potential is a function of the RuralEcoEffect and the coastal recreation potential, highlighting an important synergy between coastal and rural areas. Based on stakeholders and expert opinion, the rural recreation potential can be first promoted by attracting tourists from the coastal area.

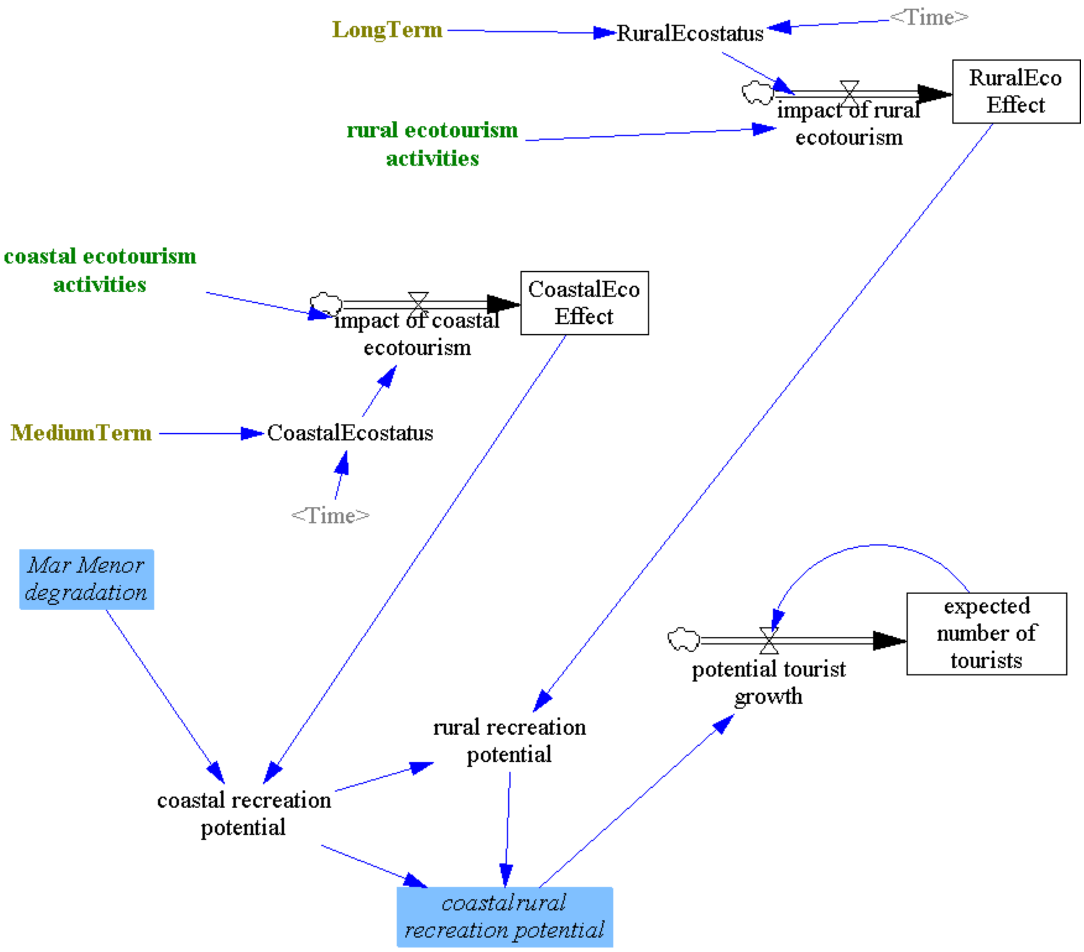


Figure 40: Stock-flow model structure for the coastal-rural recreation potential sub model.

2.6.2.6. Sub model 6: Social awareness and governance

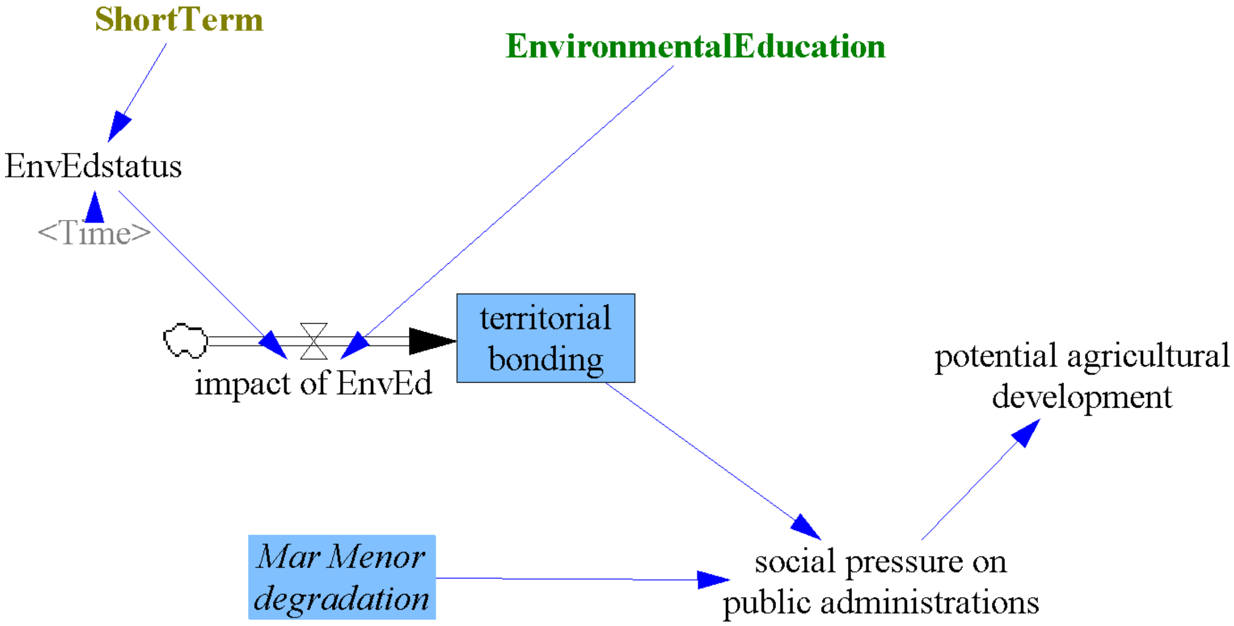


Figure 41: Stock-flow model structure for the social awareness and governance sub model. Green colour variables represent main solution scenarios. Blue boxes represent key performance indicators.

The potential agricultural development variable (Figure 41), explained in sub model 3, can also be negatively affected by the social pressure on public administrations, which is a function of the Mar Menor lagoon degradation and the territorial bonding. Environmental education is a scenario variable that goes from 0 to 1, defaulting in 0, and can be increased when the number of environmental education activities increases. This variable slowly affects territorial bonding by means of the impact of environmental education variable ("impact of EnvEd").

2.6.2.7. Sub model 7: Sustainable land management practices

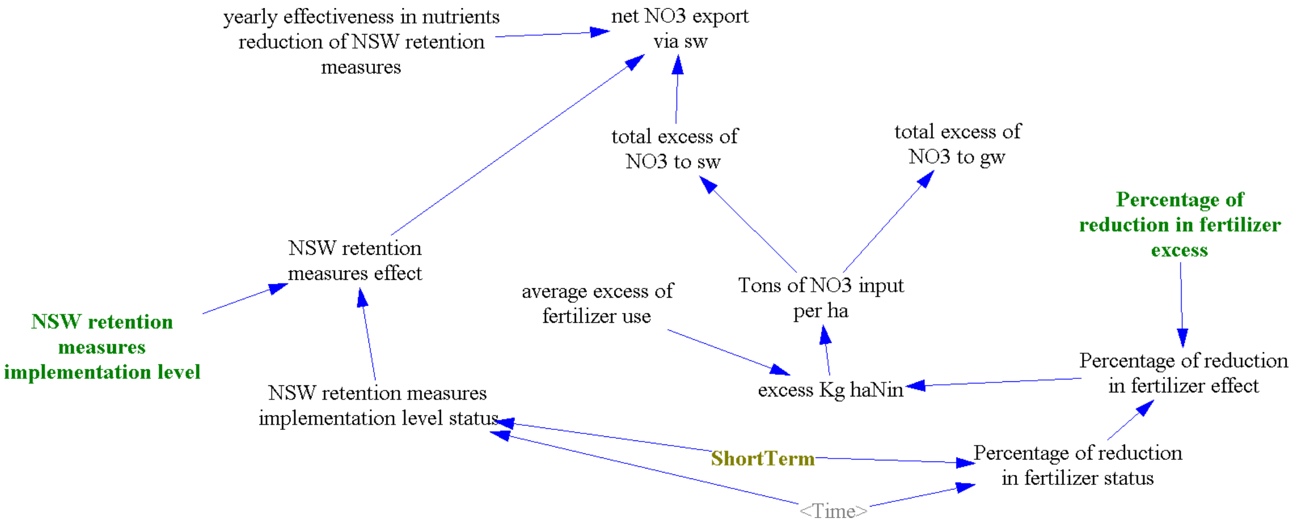


Figure 42: Stock-flow model structure for the sustainable land management practices sub model. Green colour variables represent main scenarios.

The model variable ‘excess Kg haNin’, explained as part of sub model 2, is influenced by the average excess of fertilizer use (Kg/ha of Nitrogen input) and weighted by a short-term scenario based on the percentage of reduction in fertilizer excess. This scenario influences the input of nutrients via surface- and groundwater. On the other hand, in relation to surface water nutrients input, the implementation of nutrients, soil and water retention measures is also included as a scenario (NSW retention measures implementation level; from 0 to 1, ranging from a scenario with no retention measures to a complete implementation), which affects the net NO3 export via sw by means of the yearly effectiveness in nutrients reduction of NSW retention measures (70%; Pärn et al., 2012).

2.6.3. Application: Producing a general representation of a highly complex socio-ecosystem

2.6.3.1. Application rationale

The SD model developed in COASTAL can simulate the interactions between rural-coastal areas and different related sectors like agriculture, tourism, fisheries, photovoltaic energy production, local populations, ONG and public administrations. It allows for the evaluation of the impacts of changes in the system, like the implementation of specific solutions or changes in external drivers of socioeconomic and political variables, on the Key Performance Indicators of sustainability. This makes the SD model particularly useful as a Decision Support System (DSS) to evaluate the impacts of different solution alternatives and thereby support better informed decision making.

This kind of DSS is highly relevant in the current national and regional policy context in order to evaluate the effectiveness of proposed solutions and to identify possible synergies and trade-offs between sectors that might be affected by them. At the national level, in November 2021 the Spanish Third Vice President and Minister for the Ecological Transition and the Demographic Challenge, Ms. Teresa Ribera Rodríguez, presented “The framework of priority actions for the recovery of the Mar Menor (MAPRMM), integrating several actions for the ecological recovery of the Mar Menor socio-ecosystem, with an attribution of 484 million Euros, to be implemented between 2021 and 2026. This framework targets the sustainable management of inland (rural) and coastal areas and particularly the interaction between them. At the regional level, the Regional Government of Murcia developed the ‘Integrated Management Strategy of Coastal Areas of the Mar Menor and its Surroundings’ as a general policy framework, and accepted a ‘Law for the restoration and protection of the Mar Menor (3/2020 of 27th of July 2020) that includes specific actions to protect and restore the environmental status of the Mar Menor.

A significant number of the actions integrated in the MAPRMM framework and several of those that are included in the Regional Integrated Management Strategy and the law for protection of the Mar Menor coincide with solutions included in the Business Road Map (BRM) and policy guidelines for the sustainable development of the Mar Menor and Campo de Cartagena that was developed as part of COASTAL. Examples of such solutions are:

1. the control (and compliance) of illegal irrigated areas and irrigation related activities;

2. the hydrological-forest restoration of the streams draining towards the Mar Menor to reduce flood risk and improve the environmental status of ephemeral water streams; the environmental restoration and improvement of farms;
3. the renewal of the water pumping system in the Albujón ephemeral stream for surface water pumping and treatment;
4. actions to improve the sanitation and wastewater treatment network; the protection of waters against contamination by nitrates from agricultural sources; and implementation of vegetation structures and vegetation strips to prevent runoff and erosion.

Altogether, the developed SD model provides an excellent opportunity to evaluate the impacts of the Framework of priority actions for the recovery of the Mar Menor proposed by the Minister and the Framework for Integrated Management and the Law for restoration and protection of the Mar Menor developed at Regional level. Moreover, the SD model allows for evaluation of additional measures (like promoting coastal and rural ecotourism) and for evaluation of the robustness of solutions to external drivers like climate change or changes in international socioeconomic and policy context (see Deliverable 20).

2.6.3.2. Results and discussion

Below follows a list of policy relevant opportunities and some potential limitations for the use of the SD model as a decision support tool:

1 The SD model developed for the Mar Menor lagoon and Campo de Cartagena watershed is a science-based tool that produces a general representation of a highly complex socio-ecosystem and allows for holistic analysis of impacts of multiple policy and business solutions. It includes various business sectors and relies ondata from 1961 to 2022. The model can assess impacts on Key Performance Indicators for the coming 50 years. This makes it a relevant science-based tool to support integrated management and policy of coastal and rural areas at different time horizons (short, medium and long term).

2 The SD model consists of 7 sub models covering 7 interrelated subsystems. Compartmenting the SD model in sub models eases integrating complex relations across actions and processes, stocks, flows, internal feedback loops and time delays, and allows for adding new variables, processes and sub models to the already developed SD model with limited effort. For instance, actions proposed in the MAPRMM that are currently not included in the SD model can potentially be added to the SD model to help visualize potential impacts on different key performance indicators.

3 The SD model allows evaluating business solutions and policy recommendations as well as external factors derived from different potential political, socio-economic, and climate change scenarios taking place at the global level, covering a high level of uncertainty.

4 The SD model and the Key Performance Indicators that are evaluated cover environmental, social and economic domains, showing a comprehensive but manageable overview of a highly complex socio-ecosystem. Since it does not cover all possible impacts on social, economic and environmental aspects, to include additional indicators, more data, model variables and parameters, and even model structure modifications, might be needed. Although data availability is often still a limitation to add further functionality, numerous efforts are being made in order to improve the knowledge about the functioning of very complex systems, such us the contribution of groundwater discharge affecting the

Mar Menor ecological status. For instance, the General Directorate of Water is working on the *"Improvement of the network of hydrological, geological and water quality information, and numerical modelling of the hydrological cycle and pollution, especially diffuse nitrogen and phosphorus*". Once available, these data would be of great interest to nourish the developed SD model.

5 The SD model is particularly useful to identify trends and possible feedback processes resulting in synergies or trade-offs. The model outcomes are however less useful as absolute quantitative predictors of change.

6 The model is particularly useful for the assessment of policy and business solutions since it allows for direct comparison of the impact of individual or combined solutions on the key performance indicators (KPI) that represent all sectors involved. It can be used to run "what if" simulations to test certain business solutions and policies that can greatly aid in understanding changes and impacts in the Mar Menor and Campo de Cartagena socio-ecosystem over time. In this way, the SD model can be of great help to prioritize solutions for achieving minimum sustainability standards on key performance indicators considering available resources.

3. General synthesis

3.1. Introduction: general considerations

Systems Thinking and Systems Dynamics haven proven their value for supporting policy decisions and strategic planning for structurally complex socio-environmental systems. Understanding problems from the underlying feedback structure helps identify counter-intuitive responses to policy interventions and develop innovative solutions. It was for this reason that COASTAL adopted a combination of multi-actor approaches, scenario analysis and stock-flow modelling to visualize, understand and address the challenges of land-sea synergies. By itself, system feedback, let alone stock-flow modelling, is a difficult concept to communicate. The added value for policy making is best explained by clear cut examples focusing on the outcomes of the process.

WP4 contributes to the toolbox of instruments and project outcomes aimed at making business road maps and policy recommendations **evidence based**. When developing quantitative stock-flow models one should be clear on why this type of modelling is needed, how the models can be used, and who will use the models. Quantitative (stock-flow) modelling of complex systems has important advantages (Sterman, 2000). For COASTAL the models helped to:

1. Identify and remove inconsistencies in the complex mind maps of land-sea interactions are revealed automatically,
2. Make policy and business recommendations "evidence-based".
3. gain more in-depth understanding of the role of land-sea interactions and impact of system feedback on system behaviour;
4. stress test policy and business decisions while visualizing the impact on key indicators, including a 'flight simulator' dashboard added to the 14 models.

System innovation can be supported by applying the models to identify counterintuitive response to planned policy decisions, to obtain understanding of the role of the feedback structure, and to anticipate tipping points. This all comes at a cost. Effort and expertise are needed for designing and implementing the models and collecting the necessary data. In addition, the validity of the models should be explained to stakeholders as part of the confidence building process. This can be a challenge when model development is still in progress, or when model complexity reduces the communication value of the models.

Strengths of the current COASTAL model library can be summarized as follows:

a) Together the **graphical interface** and **policy dashboard** of the models surpass research models in communication value, although additional documentation and tutorial examples are needed for the more complex models;
b) All SD models allow rapid policy analysis while the data demands are limited;

c) The modelled priorities, key stock variables, scenario drivers and policy indicators were identified **based on direct engagements** with a broad selection of over 500 stakeholders, in interactive, holistic settings covering a wide range of themes across the land-sea interface (agriculture, water management, renewable energy, tourism, spatial planning, ….);
d) All models were systematically **screened** in terms of design, completeness and usefulness (see Annex 2) and passed tests to verify the **consistency of equations and dimensions**;
e) Where possible, the complexity of the models and model scope has been addressed by a **modular design** of the models, with interconnections between sub models managed in separate 'views' or highlighted model fragments;
f) Model **granularity has been minimized** to the extent possible, i.e. the models are well-balance in terms of the level of detail throughout the model. This increases the model transparency;
g) **Flexibility of the models** for making adaptations to the model structure, model equations, scenarios, parameter settings and other data is relatively easy due to the modular model structure, use of external files for data management, and high degree of model granularity;
h) Though stock-flow modelling is a technical expertise the stock-flow models or underlying principles have been **communicated to the stakeholders and discussed** to identify any potential for improvement or adjustment of the models;
i) All models were developed in the VenSim® **common software platform** for SD modelling, enabling interoperability of models and exchange of reusable model constructs. Runtime versions can be shared with third parties or stakeholders for further distribution;
j) A **complete and harmonized documentation** of the model equations, variables and parameters has been generated automatically, and can be found this document.

The following **general recommendations** are made to facilitate future model development, maintenance, testing, reuse and intercomparison:

- Modelling guidelines should not only address the general principles of SD modelling and technical functionalities of the software used but also **provide specific guidance** with respect to the number of variables to use, data handling, and consideration for important model features affecting the dynamics and potentially the usefulness of the model such as system feedback, time delays and systemic limitations. The use of stock, flow, and auxiliary variables should be proportional;
- **Dimensional consistency** is important for ensuring the validity of equations and supported by most SD modelling software, including VenSim®;
- Model development should be a **gradual step-by-step process** with ample room for intercomparison of models developed in a project, serving a mutual learning process. It is not a bad idea to start from generic archetypes. Furthermore, stock-flow modelling should start as soon as possible with quantitative policy analysis as an objective, it can go hand-in-hand with conceptual analysis;
- Model developers should be made aware that a broad scope and structural complexity of their models are not goals in themselves and can affect the workload for model testing and other work

tasks such as the integration with scenario analysis and policy analysis. Keep models as simple as possible, but not any simpler (dixit Albert Einstein);

- Complex, repetitive numerical calculations cannot always be avoided (for example array operations). It is possible to include these directly in SD models, but the design may benefit from keeping these separately in external input files. This depends on the degree of system feedback between the main model and these data.
- As much as possible, **model dynamics should be endogenous** i.e. generated by the feedback structure of the model rather than by the time series imported from data files;
- **Graphical design** of these models is often a concern in terms of the communication value. However, one should realize that end-users and stakeholders are generally more interested in the model outcomes and policy recommendations rather than the underlying models as long as there is confidence in the model. Overly complex models are more a concern in terms of model design, maintenance and certainly reuse.
- Testing of structurally complex SD models with a broad scope is often a challenge. Here, it can be useful to export the model results to other software platforms allowing more rapid analysis (R, MatLab®, Python, ...).

3.2. Experience and Lessons learned by the different MALs applying SD modelling in Coastal

3.2.1. Introduction

In the following chapters we summarise the main points addressed by the different MALs in paragraphs 2.1 to 2.6. The was on practical applicability of the models taking into account the interaction with the stakeholders / emphasis actors (3.2.2), the relation to existing legislation *i.e.* the model is addressing problems that are practically relevant for the MAL (3.2.3) and finally an assessment of the model and possible improvements (0).

3.2.2. Communication with actors and stakeholders

In the context of ensuring that the modelling is policy relevant, communication is essential between the modelling teams and the actors and stakeholders. All MALS stress that their models were developed in close cooperation with the stakeholders and are based on the analysis and the CLDs that were established in WP1.

In case actor partners or stakeholders were familiar with modelling, some model developers were faced with difficulties explaining the added advantage of an SD model compared to a detailed operational model. A case in point is the water management model in MAL 1 where actor and stakeholder partners were familiar with an existing, detailed numerical water balance model for the same area. It was then difficult to convey to the users the purpose of a less detailed SD model. The SD model which is intended to support the long-term debate and does not only account for water management but also other, intertwined processes. Another, related problem observed in MAL1 is that in the discussions to define the model scope for the off shore wind energy sector, users familiar with operational models for short term technical engineering and financial problems were not immediately inclined to consider the implications of long term decommissioning planning, a topic for which currently no model was apparently available. The fact that the SD models are inherently less detailed, and their results should not be considered as absolute values is acknowledged by the MAL6 participants.

In all MALs the model results were presented and discussed with the stakeholders and actors. The models can in the discussions not only provide quantitative results to assist decision making but can also be:

- a discussion platform where it takes on the role of an objective, common ground to reconcile opposing views based on quantified data and a holistic view (MAL4);
- a training tool: in MAL5 the model will be the basis of the Design and setup Training Courses for the Operational Program Administrative Capacity POCA/399/1/1: Improving the capacity of the central public authority (Ministry of Environment & Waters) in the field of Integrated Coastal Zone Management (ICZM). In this respect the model is seen both as a means to convey information as a tool for training and to support decision makers by considering long term impacts of interwoven activities;

3.2.3. Model relationship to other initiatives and existing frameworks and legislation

MAL1

By considering impacts of climate change on the agricultural water demand under different crop schemes the water management model is particularly useful in the context of the Water Framework Directive (WFD) while the work on offshore wind energy can contribute to achieving the EU climate goals.

MAL2

The model is compatible with the Water Framework Directive (2000/60) and the defined Regional Management Action Plans for the catchment area, the Strategic Development Program of the Peloponnese Region (Eydpelop) that has been developed as part of the National Strategic Development Framework (ESPA) and the Common Agricultural Policy (CAP), Special Environmental Study and Management Plans for the Natura2000, Farm to Fork Strategy

MAL3

The model results are intended for use in the context of Swedish policy and actions to achieve the WFD and BSAP objectives.

MAL4

There are as with the previous MALs links to the WFD as the model can be used to quantify how to deal with water shortages and how each of the water sinks can contribute to the solution and what the consequences are of the choices that are made. The model for the effects of adopting more sustainable agricultural practices can contribute to the Farm2Fork Strategy.

MAL5

One of the main added values of the tool is that it covers a science-policy niche and can help the debate on the long-term impacts of integrated sectoral activities development and give support for decisions making process in various national and international environments, such as ministerial thematic groups, European initiatives and strategic plans design.

MAL6

The model can be used to support the implementation of both the national framework of priority actions for the recovery of the Mar Menor(MAPRMM) and 'Integrated Management Strategy of Coastal Areas of the Mar Menor and its Surroundings' developed by Regional Government of Murcia as it considers many of the actions included in the framework and the strategy.

3.2.4. General assessment of model value by the MALs and ideas for enhancements

MAL1

For MAL1 it turned out difficult to identify a clear-cut model scope and convince the actors and stakeholders of model utility. In the end the model for water management was considered to be incomplete and results could only be partially used. In a follow up project, it will be necessary to investigate how the model could be further developed. For the decommissioning model the added value is that it covers a science-policy niche and can help turn the debate more to the long-term logistic impacts of offshore renewable energy in an intuitive manner.

MAL2

The MAL2 participants see a clear link between the model they developed and the different legislative and operational frameworks and actions in the area with respect to environmental conservation, sustainable agriculture and tourism.

MAL3

The model results are used to demonstrate the importance of legacy sources. Implications of these results for management measures have been discussed with the local partners in the context of Swedish policy and actions to achieve the WFD and BSAP objectives. The emergent dominant role of legacy sources for water quality and eutrophication problems in the MAL3 case, and the policy issues that arise from this, are not specific to this Swedish case and are also relevant for other regions such as France.

MAL4

The water balance model is capable of quantifying water shortage problems and how each of the water sinks can contribute to a solution and what the consequences are of the choices that are made. The MAL4 model can also demonstrate that a shift towards more sustainable practices does not necessarily result in economic loss albeit by assuming consumers will increase their budget to match the higher produce prices. The latter is currently missing in the model but could however be included in the model.

MAL5

As experience setting up and using SD models was initially non-existent the modest results obtained using the SD modelling for this MAL were limited. However, even a clear analysis of the problem(s) at hand based on feedback from all those involved was initially missing and this is indeed one of the outcomes of the project for this MAL. While this might seem trivial, an essential step in any quantification of the problems faced in the area will require such an analysis. So, one of the main outcomes is in this case the analysis underpinning the SD model development process in which two separate institutes collaborated. The participants also see clear options for exploitation of the model results where the model is seen both as a means to convey information as a tool for training and to support decision makers by considering long term impacts of interwoven activities.

MAL6

The MAL06 team sees a role as a Decision support system for their SD model. The model for MAL6 considers many but not all of the actions in the national framework MAPRMM and the 'Integrated Management Strategy of Coastal Areas of the Mar Menor and its Surroundings' developed by Regional Government of Murcia. The modular structure of the model facilitates adding the actions from the national framework and regional strategy plan are not considered currently.MAL6 The team while acknowledging that the model in its current state addresses problems accounting for both environmental, social and economic aspects, does seem limitations and sees a need for further development. They conclude that the model is useful for identifying trends but that the results should not be considered absolute quantitative predictors.

3.3. Role of the Knowledge Exchange Platform

Before models can be distributed, they should be self-explaining, made available together with the required input data, documented in an appropriate manner, validated and tested to run without technical errors or other anomalies. Considerable effort was already made by the MALs to address these requirements. For example, all models were fitted with a "policy dashboard" providing an overview of the key policy indicators and control levers so the models can be set without a need to tinker with the underlying model structures. Depending on the level of complexity and scope of the models, direct reuse to a different context or region is generally not feasible without significant modification. However, generic and reusable model constructs or system archetypes can be derived from or were already used in the models. These are expected to be of more value for facilitating the design of new model applications. This is the focus of work task 4.3 – Generic Toolbox – and deliverable D15.

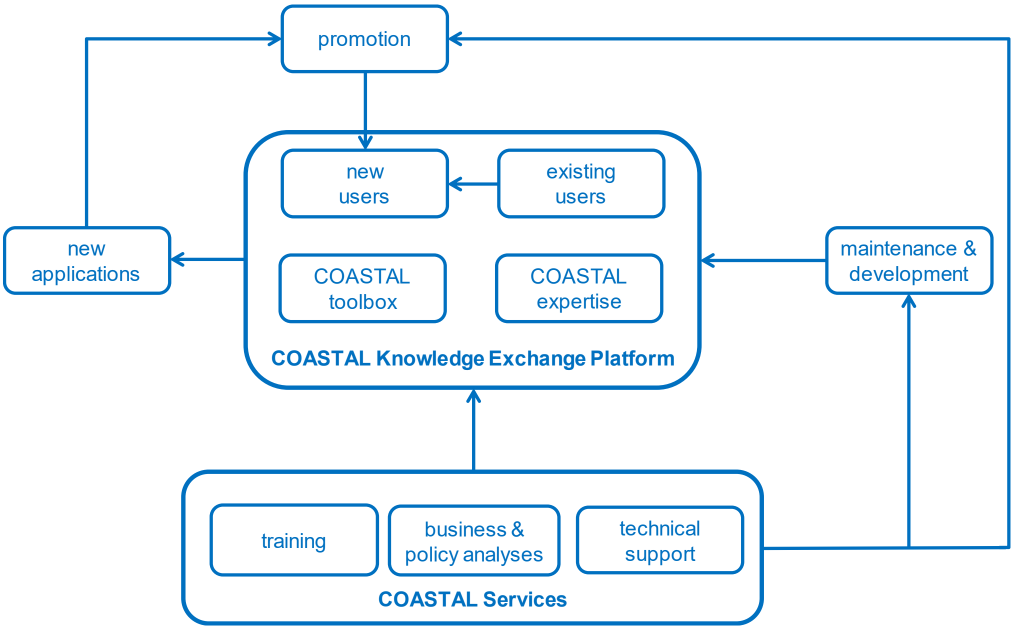


Figure 43: Proposal for post-project maintenance, development and promotion of the COASTAL toolbox and models.

The role of the Coastal Knowledge Exchange Platform (Figure 43) can lie in the exchange, reuse and development of SD models for supporting coastal-rural policy making and business decisions. This should then be supported by training programs and capacity building. All final stock-flow models are made available following the FAIR guidelines through the Zenodo Open Data Platform (https://zenodo.org/communities/773782-coastal/).

With respect to the models the COASTAL Knowledge Exchange Platform foresees the provision of:

- fully documented, synergistic SD models, including tutorial applications and base data;
- a toolset of SD model constructs, consisting of generic feedback structures, response functions, and modelling guidelines

and linked to those models and their results:

- direct online access to the tutorial tools and example applications for demonstrating the principles and potential of the COASTAL methodology;
- technical support services to facilitate the use and adaptation of existing tools, and design and implementation of new applications to support land-sea collaboration;

4. Bibliography

Access to models on the Zenodo Open Data Platform: https://zenodo.org/communities/773782-coastal/

Baboianu G. (2016) Danube Delta: The Transboundary Wetlands (Romania and Ukraine). In: Finlayson C., Milton G., Prentice R., Davidson N. (eds) The Wetland Book. Springer, Dordrecht.

Baresel, C., Destouni, G. 2005. Novel quantification of coupled natural and cross-sectoral water and nutrient/pollutant flows for environmental management. Environmental Science and Technology, 39, 6182-6190.

Basu, N. B., Van Meter, K. J., Byrnes, D. K., Van Cappellen, P., Brouwer, R., Jacobsen, B. H., ... & Olsen, S. B. (2022). Managing nitrogen legacies to accelerate water quality improvement. Nature Geoscience, 15(2), 97-105.

Berg, H.; Maneas, G.; Salguero Engström, A. A Comparison between Organic and Conventional Olive Farming in Messenia, Greece. Horticulturae 2018, 4, 15.

Bring, A., Asokan, S.M., Jaramillo, F., Jarsjö, J., Levi, L., Pietroń, J., Prieto, C., Rogberg, P., and Destouni, G. (2015a). Implications of freshwater flux data from the CMIP5 multi-model output across a set of Northern Hemisphere drainage basins. Earth's Future, 3(6), 206–217.

Bring, A., Rogberg, P., and Destouni, G., (2015b). Variability in climate change simulations affects needed long-term riverine nutrient reductions for the Baltic Sea. Ambio, 44, S381–S391.

Cseh, M. 2009. Multi-approach comparison of nutrient flow modeling in the Norrström drainage basin. Master thesis of Environmental Engineering, Budapest University of Technology and Economics, Budapest, Hungary and Stockholm University, Stockholm, Sweden.

Darracq, A., Greffe, F., Hannerz, F., Destouni, G., and Cvetkovic, V. (2005). Nutrient transport scenarios in a changing Stockholm and Mälaren valley region. Water Science and Technology, 51, 31-38.

de Kok, J.L, Viaene, P. , Karageorgis, A., Panagopoulos, Y. Kastanidi, E., Destouni, G., Kalantari, K., Seifollahi, S., Maneas, G., Othoniel, B., Lescot, J.M., Phelpin-Leccia, O., Vernier, F., Lazar, L., Rodino, S. Pop, R., de Vente, J., Albaladejo, J., Martinéz-López, J., D'Haese, N., Notebaert, B., De Pauw, B., Dauwe, S., Van Isacker, W. Deliverable D14 Operational SD Models for Coastal-Rural Interactions - Case Study Level H2020-COASTAL. Grant Nr. 773782. h2020-coastal.eu 2021.

Destouni, G., Fischer, I., and Prieto, C. (2017). Water quality and ecosystem management: Data-driven reality check of effects in streams and lakes. Water Resources Research, 53, 6395-6404. Doubleday/Currency. Second Ed. 2006.

Destouni, G., and Jarsjö, J. (2018). Zones of untreatable water pollution call for better appreciation of mitigation limits and opportunities. WIREs Water, e1312.

Elmhagen, B., Destouni, G., Angerbjörn, A., Borgström, S., Boyd, E., Cousins, S. A. O., Dalén, L., Ehrlén, J., Ermold, M., Hambäck, P. A., Hedlund, J., Hylander, K., Jaramillo, F., Lagerholm, V. K., Lyon, S. W., Moor, H., Nykvist, B., Pasanen-Mortensen, M., Plue, J., Prieto, C., van der Velde, Y., and Lindborg, R. (2015). Interacting effects of change in climate, human population, land use, and water use on biodiversity and ecosystem services. Ecology and Society, 20(1), Art. 23.

Engström A. S. (2017). A comparison of conventional and organic olive farming in the catchment area of Gialova Lagoon, south-west Greece. MSc Thesis, Dept. Physical Geography, Stockholm University, Sweden.

HELCOM, 2010. Helsinki Commission (HELCOM). Ecosystem health of the Baltic Sea – Initial HELCOM holistic assessment 2003-2007. Baltic Sea Environment Proceedings 122, ISSN 0357 - 2994, pp. 68. Available at (accessed on 11 June 2021): https://helcom.fi/wp-content/uploads/2019/08/BSEP122.pdf

HELCOM, 2018. Helsinki Commission (HELCOM). State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Baltic Sea Environment Proceedings 155, ISSN 0357-2994, pp. 155. Available at (accessed on 12 February 2021): https://helcom.fi/media/publications/BSEP155.pdf

Institutul Mational de Cercetare-Dezvoltare Martina "Grigore Antipa" (2018). Studiu privind elaborarea raportului privind starea ecologică a ecosistemului marin Marea Neagră conform cerinţelor art. 17 ale Directivei Cadru Strategia pentru mediul marin (2008/56/EC).

Klein, J., Ekstedt, K., Walter, M.T., Lyon, S.W. Modeling Potential Water Resource Impacts of Mediterranean Tourism in a Changing Climate. Environ. Model. Assess. 2015, 20, 117–128.

Le Moal, M., Gascuel-Odoux, C., Ménesguen, A., Souchon, Y., Étrillard, C., Levain, A., ... & Pinay, G. (2019). Eutrophication: a new wine in an old bottle?. Science of the Total Environment, 651, 1-11.

Le Monde avec AFP. (2022). Dans les Deux-Sèvres, des heurts avec la gendarmerie lors d'une manifestation contre les « mégabassines ». Le Monde. https://www.lemonde.fr/planete/article/2022/03/26/dans-les-deux-sevres-des-heurts-avec-la-gendarmerie-lors-d-une-manifestation-contre-les-megabassines_6119297_3244.html

Maneas, G., Makopoulou, E., Bousbouras, D., Berg, H., and Manzoni, S. (2019). Anthropogenic changes in a Mediterranean coastal wetland during the last century-the case of Gialova Lagoon, Messinia, Greece. Water 11:350. doi: 10.3390/w11020350.

Manzoni, S., Maneas, G., Scaini, A., Psiloglou, B. E., Destouni, G., and Lyon, S. W. (2020). Understanding coastal wetland conditions and futures by closing their hydrologic balance: the case of Gialova Lagoon, Greece. Hydrol. Earth Syst. Sci. 24, 3557–3571. doi: 10.5194/hess-24-3557-2020.

Morote, A. F., Olcina, J., and Rico, A. M.: Challenges and pro- posals for socio-ecological sustainability of the Tagus-Segura Aqueduct (Spain) under Climate Change, Sustainability, 9, 2058, https://doi.org/10.3390/su9112058, 2017.

Padazis C. (2018). Groundwater dependent ecosystems of coastal aquifers. The case of Gialova hydrosystem (Messinia, Greece) MSc Thesis, School of Rural Surveying and Geoinformatics Engineering, National Technical University of Athens, Greece.

Pellicer-Martínez, F., Martínez-Paz, J.M., 2018. Climate change effects on the hydrology of the headwaters of the Tagus River: implications for the management of the Tagus–Segura transfer. Hydrol. Earth Syst. Sci. 22, 6473–6491. https://doi.org/10.5194/hess-22-6473-2018.

Petrisor, A.-I., Petre, R., Meita, V. (2016). Difficulties in achieving social sustainability in a biosphere reserve. INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE Volume 7, Issue 1, January-March 2016: 123-136.

Préfet de la Charente-Maritime. (2022). Gestion de l’eau - Cellule de vigilance « Sécheresse » du 16 mai 2022. https://www.charente-maritime.gouv.fr/Politiques-publiques/Environnement-risques-naturels-et-technologiques/Eau-et-milieux-aquatiques/Gestion-quantitative-de-la-ressource/CP-Gestion-de-l-eau-Cellule-de-vigilance-Secheresse-du-16-mai-2022/Gestion-de-l-eau-Cellule-de-vigilance-Secheresse-du-16-mai-2022.

Sbarcea, M., Petrisor, A-I, Petrisor, L.E., (2019) Mapping Potential Environmental Conflicts in the Danube Delta Biosphere Reserve. Scientific Annals of the Danube Delta Institute, Vol.24, https://doi.org/10.7427/DDI.24.19.

Seifollahi-Aghmiuni, S., Destouni G., Kalantari Z., Viaene, P., D’Haese, H., De Kok J.-L. , Kastanidi E., Karageorgis, A., Panagopoulos Y., Maneas G., Lescot J.-M., Vernier F. Lazar L., Rodino, S., Pop, R., Martínez-López, J., De Vente, J., and Albaladejo J. Knowledge Transition. COASTAL Deliverable D07. Grant Nr. 773782. h2020-coastal.eu December 2020. h2020-coastal.eu

Skokou N., Chlykas N., Deliverable PB3. «Management Measures for the “Biodiversity Protection Area of Pylos Lagoon (Divari), Sfaktiria Island, Akrotiri Akrita, Sea Area of South Messinia and Oinousses Islands”». Min. Of Environment.

Sterman John D. Business Dynamics: Systems Thinking and Modeling for a Complex World, McGraw Hill, 2000.

Tiller R. , De Kok J.L., Notebaert B., Wouters N., Stubbe F., Motmans S., Stubbe W., Dauwe S., Pirlet H., Vernier F., Lescot J.M., Prou J., Fort J.L., Sabatié S., Lazar L., Timofte F., Nenciu M.I., Golumbeanu M., Destouni G., Seifollahi-Aghmiuni S., Kalantari Z., Prieto C., Chen Y., Maneas G., Kastanidi E., PanagopoulosI., Karageorgis A., Guittard A., Berg H., Martínez-López J., De Vente J., Boix-Fayos C. , and Albaladejo J. Sectoral Analysis of Coastal and Rural Development. COASTAL Deliverable D03. H2020-COASTAL. Grant Nr. 773782. h2020-coastal.eu February 2019

Tiller, R., Destouni, G., Golumbeanu, M., Kalantari, Z., Kastanidi, E., Lazar, L. , Lescot, J.M., et al. 2021. “Understanding Stakeholder Synergies Through System Dynamics: Integrating Multi-Sectoral Stakeholder Narratives Into Quantitative Environmental Models.” Frontiers in Sustainability 2 (November): 1–12. https://doi.org/10.3389/frsus.2021.701180. 2021.

World Bank (2014a) REPORT 2.2 Draft Danube Delta Integrated Sustainable Development Strategy (2030), https://www.mlpda.ro/userfiles/delta_dunarii/draft_Danube_Delta_Strategy.pdf.