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Modelling crop-growing stages in CLEWs V.3

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We use this protocol and it's working

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Abstract

In a CLEWs model for each land-use, the amount of water that goes in (precipitation and irrigation if needed) is equal to the output (evapotranspiration, runoff, and groundwater recharge). Previous CLEWs studies modelled land water requirements using yearly averages. However, despite this simplification is true for land covers where the vegetations regenerates naturally (such as forest, grassland and water bodies), water needs, and therefore outputs, can change greatly for cropland. Land used for growing crops has an intra-annual variability since crops are planted and harvested regularly within the year. Depending on the season, crops' water requirements can be three times more if we are in the growing stage than the harvested phase. Rainfall precipitation patterns are forecasted to increase their variability due to climate change impact. The increased variability might lead to a mismatch in water availability and supply if water scarcity occurs when there is a higher water requirement from the crops. Because of that, we modelled seasonal crop-growth stages in order to represent variable water demand.

Image Attribution

Figure 1 Adding seasons in the CLEW reference system. The figure represents a schematic overview of the water balance represented in OSeMOSYS for a general crop (LNDCROP). On the left-side, we see the inputs to that technology: precipitation, land, season1 and season 2. On the right-side we see the output: evapotranspiration, groundwater, surface water, and crop demand. For each technology (represented as a square), there are two modes of operation associated (continued line or dotted line) which have to be consistent to the season represented (see section below). **Figure 2** Harvested area in Season 1 (left) and Season 2 (right). The figure represents on the vertical axis the total harvested area in 1000 sq. Km, while on the horizontal axis, it represents its development through the modelled years. The horizontal axis is further divided into two sub-sections namely REF 1 and REF 2 which represents the behaviour of the two modes of operation: mode 1 and mode 2 (representing respectively growing and harvesting season).

Guidelines

For each modelled season, we increased the modes of operations. Since in this case they were two, we will show the model set-up with two modes of operations. Note that it is possible to increase the number of modelled seasons and modes, but this will lead also to increased model complexity and computational requirements. To each season-technology is associated a commodity, called S1 and S2. These commodities go into cropland uses, but the value of the input activity ratio varies according to the mode of operation. Each mode of operation (MoO) is associated with a season: in this case MoO 1 refers to Season 1 and MoO 2 to Season 2. This set-up has to be consistent for modelling all the water cycle. Another key factor of the modelling consists in associating a capacity factor to each season-technology. The capacity factor has to be 1 for the time slice that represents the season and 0 for the other one. This will force the land technology to switch between Season 1 and 2 changing water requirements and water outputs accordingly. One of the main challenges in modelling crop growing stages, is to ensure consistency in harvested area. The goal is to ensure that the same amount of land is allocated for every crop across the regions since the only variable must be the water cycle. The first step consists of keeping for both modes the same crop yield. OSeMOSYS is a demand driven model. Even if harvesting happens in the late stage (Season 2), OSeMOSYS uses linear optimization for minimizing the system's costs and there is therefore a linear relationship between the technology's outputs commodities. Moreover, unlike other CLEWs model, all the croplands will have 1 year as operational life and no capital costs. The reason is because it is important to ensure consistency between capacity and activity. For instance, if a land technology has 15 years of operational life, the installed capacity will last for 15 years. However, depending on the optimization process, the technology can either produce (activity = capacity), or it can be substituted by another technology that is replacing the former one (there is new capacity from another technology and therefore the former might face a decrease in the activity). In previous CLEWs model this set up was possible due to the annual average values used for characterizing cropland. In this case, we need to make sure that if there is "installed capacity" of a given crop, it is consistent across the seasons. Fully exploiting the capacity is therefore needed for avoiding having two optimized land-uses across the seasons. Because of the importance in keeping the consistency across the seasons, all the calibration was done using only the activity instead of the capacity. The reference year is characterized by a lower and upper annual activity limit (the upper limit and the max capacity can be 1% higher than the lower to avoid infeasibilities), and by a maximum capacity equal to the upper activity limit in order to make sure that the reference year respects the land-use calibration. After the first year, the model is calibrated using the parameters Technology Activity Decrease By Mode Limit and Technology Activity Increase By Mode Limit. Note that it is important to assign the same values for both modes of operations. Finally, each technology is characterized by Fixed and Variable costs. Note that also the Variable costs have to be assigned for both modes. The capital costs are zero because we set 1 as Operational Life, assuming that the cost of buying land does not vary across crop types.

Materials

MUIO - OSeMOSYS User Interface

Prerequisites

- 1 Know how to design a simple CLEWs model. You can find more information on: <https://www.open.edu/openlearncreate/course/view.php?id=16186>

Before you start

- 2 Ensure you have calculated already (e.g on a separate Excel sheet) all the data you need for quantifying water inputs and outputs of each crop growing stage.
- 3 Ensure you have installed on your computer the MUIO v5 or higher

General methodological overview

4

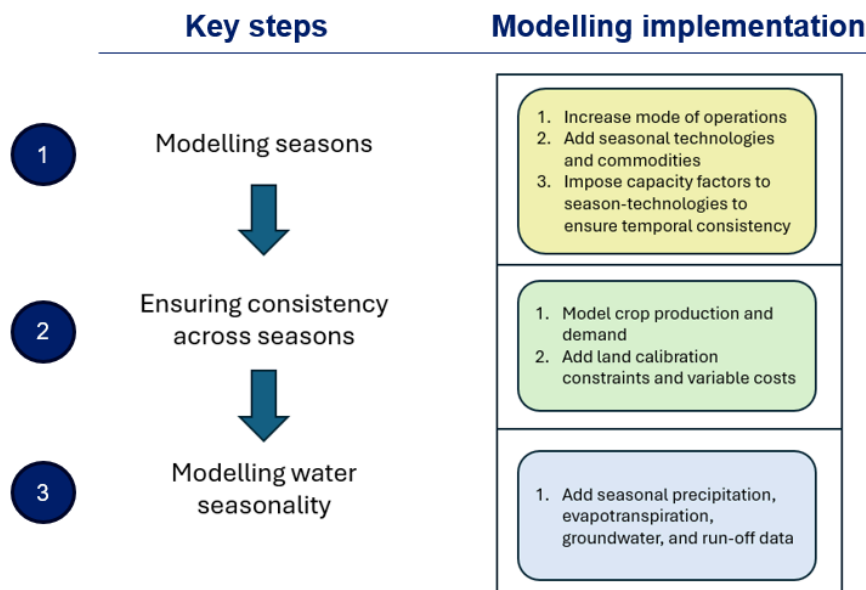


Figure 1 Key steps for modelling water seasonality and crop-growing stages in OSeMOSYS

Step 1 - Modelling seasons in OSeMOSYS (case with 2 seasons)

- 5 **Increase the modes of operation**

For each modelled season, increase the modes of operations. In this case they are two, so we will show the model set-up with two modes of operations. Having a mode of operation for each season allows modellers to characterize different water cycles.

MUIO set up:

Configure the model → Model data → Modes of operation

Update the model once you are done.

Note that it is possible to increase the number of modelled seasons and modes, but this will lead also to increased model complexity and computational requirements.

6 **Create seasonal technologies and commodities**

In this case the seasons will be called Season 1 and Season 2 corresponding to the growing and harvesting phase of crop-land.

MUIO set up:

Configure the model → Technologies → add:

Season1 = Growing season

Season2 = Harvesting season

Configure the model → Commodities → add:

S1

S2

Update the model once you are done.

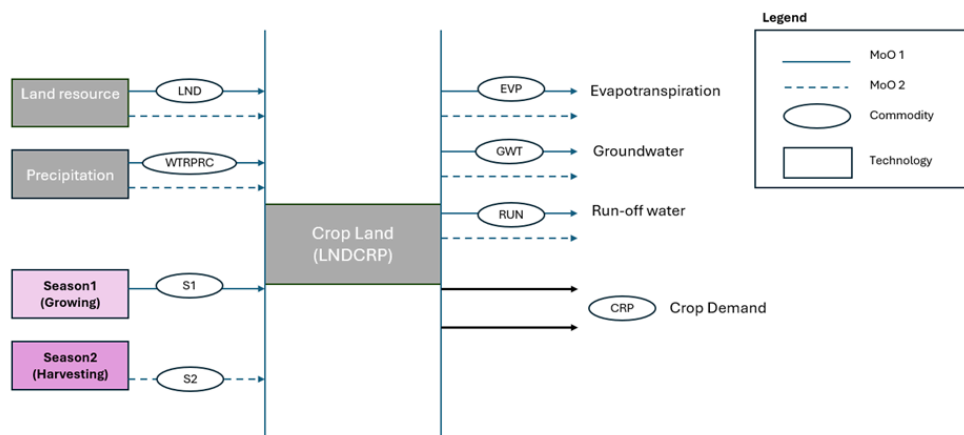


Figure 2 Schematic reference system of the seasonal water balance represented in OSeMOSYS.

The figure represents a schematic overview of the water balance represented in OSeMOSYS for a general crop (LND CRP). On the left-side, we see the inputs to that technology: precipitation, land, season1 and season 2. On the right-side we see the output: evapotranspiration, groundwater, surface water, and crop demand. For each technology (represented as a square), there are two modes of operation associated (continued line or dotted line) which have to be consistent to the season represented (see section below).

7 Set up seasonal output activity ratios

MUIO set up:

Configure the model → Technologies → Output Activity Ratio Only for season technologies Season1 and Season2

Technolo	Description	Technol...	Unit of ...	Unit of ...	Input Activit...	Output Activ...	Inj
Season 2	Harvesting		GW	PJ		S2	
Season 1	Growing		GW	PJ		S1	

Figure 3 Seasonal output activity ratios - model set up

*The figure has been created using **MUIO v.5.3** user interface*

Data entry → Output activity ratio → Season 1, Season 2 equal to 1 only to the corresponding seasonal mode.

If for example the water balance of season 1 is represented by mode 1, the output activity ratio=1 is ONLY for mode one;
if season 2 is represented by mode 2, then the output activity ratio = 1 ONLY for mode 2.

Output Activity Ratio Region, year, technology, commodity, mode of operation

Output Activity Ratio

Scenario	Technology	Commodity	MoO	Unit	2020	2021	2022	2023
SC_0	Season2	S2	1	PJ/PJ	0.000	0.000	0.000	0.000
SC_0	Season2	S2	2	PJ/PJ	1.000	1.000	1.000	1.000
SC_0	Season1	S1	1	PJ/PJ	1.000	1.000	1.000	1.000
SC_0	Season1	S1	2	PJ/PJ	0.000	0.000	0.000	0.000

Figure 4 Seasonal output activity ratios - data entry

The figure has been created using **MUIO v.5.3** user interface

8 Set up seasonal input activity ratios for crop-land

S1 and S2 go into cropland, but the value of the input activity ratio varies according to the mode of operation. In this case MoO 1 refers to Season 1 and MoO 2 to Season 2.

This set-up has to be consistent for modelling all the water cycle.

MUIO set up:

Configure the model → Technologies → Input Activity Ratio

Technolo	Description	Technolo...	Unit of ca...	Unit of ac...	Input Activity R...	Output Activity...
LNSDORLR01	Default technology	C01	10 ³ km ²	10 ³ km ²	S2,S1,WT...	WTRRUN01,WT...
LNSDORH...	Default technology	C01	10 ³ km ²	10 ³ km ²	Looking for	WTRRUN01,WT...
LNSDORLI01	Default technology	C01	10 ³ km ²	10 ³ km ²	☒ S2	WTRRUN01,WT...
LNSDORHI01	Default technology	C01	10 ³ km ²	10 ³ km ²	☒ S1	WTRRUN01,WT...

Figure 5 Seasonal output input ratios - model set up

The figure has been created using **MUIO v.5.3** user interface

Data entry → Input activity ratio → input 1 for MoO 1 if the commodity is S1 and 1 for MoO 2 if the commodity is S2

Scenario	Technology	Commodity	MoO	Unit	2020	2021
SC_0	LNDSORLR01	S1	1	PJ/10 ³ k...	1.000	1.00
SC_0	LNDSORHR01	S1	1	PJ/10 ³ k...	1.000	1.00
SC_0	LNDSORLI01	S1	1	PJ/10 ³ k...	1.000	1.00
SC_0	LNDSORHI01	S1	1	PJ/10 ³ k...	1.000	1.00
SC_0	LNDCOFI01	S1	1	PJ/10 ³ k...	1.000	1.00

Figure 6 Seasonal input activity ratios for S1 - data entry

The figure has been created using **MUIO v.5.3** user interface

Input Activity Ratio

Scenario	Technology	Commodity	MoO	Unit	2020	2021	2022	2023	2024	2025	2026	2027
SC_0	LNDMAIH01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SC_0	LNDMAIL01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SC_0	LNDMAIHR01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SC_0	LNDMAILR01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SC_0	LNDBRLHI01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SC_0	LNDBRLLI01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SC_0	LNDBRLHR01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SC_0	LNDBRLLR01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SC_0	LNDCERHI01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SC_0	LNDCERLI01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SC_0	LNDCERHR01	S2	2	PJ/10 ³ k...	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Figure 7 Seasonal input activity ratios for S2 - data entry

The figure has been created using **MUIO v.5.3** user interface

9 Set a capacity factor to each season-technology.

Crop-growing stages and the seasonal variability need to be consistent with the model temporal set-up.

In OSeMOSYS we define the temporal resolution with the "Time-Slices" which are the time split of each modelled year. The duration of each time-slice is defined by the parameter "Year-Split".

With the capacity factor, we impose the seasonal technologies to "work" only during the corresponding season. Here it is also crucial to maintain consistency across seasons and modeled time slices. The capacity factor has to be 1 for the time slice that represents the season and 0 for the other one. This will force the land technology to switch between Season 1 and 2 changing water requirements and water outputs accordingly.

Let's assume we have 6 time-slices: S11,S12,S13,S21,S22,S23.



While the second numbers (1,2,3) represent daily time, the first number (1,2) represents seasons. The capacity factors will be the following:

Technology	CF S11,S12,S13	CF S21,S22,S23
Season1	1	0
Season2	0	1

Figure 8 Capacity factors (CF) for seasonal technologies

Step 2 - Ensuring consistency across seasons

10 Consistency across seasons of crop harvested area

One of the main challenges in modelling crop growing stages, is to ensure consistency in harvested area across seasons. The goal is to ensure that the same amount of land is allocated for every crop across the regions since the only variable must be the water cycle.

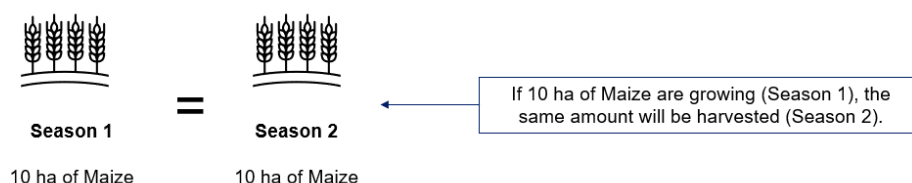


Figure 9 Consistency across seasons

11

The crop yield

OSeMOSYS is a linear optimization, demand-driven tool. Although crops produce output only during the harvesting season, setting the output activity ratio to zero in non-harvest

seasons would prevent land from being allocated in those seasons, as no demand is being supplied.

MUIO set up:

Data entry → Output Activity Ratio → Paste the same values in MoO 1 to MoO 2 → Save data

Output Activity Ratio Region, year, technology, commodity, mode of operation

Output Activity Ratio

Scenario	Technology	Commodity	M	Unit	2020	2021	2022	2023	2024
SC_0	LNSORLR01	CRPSOR	1	MTon/1...	0.253	0.253	0.253	0.253	0.253
SC_0	LNSORHR01	CRPSOR	1	MTon/1...	0.646	0.646	0.646	0.646	0.646
SC_0	LNSORLI01	CRPSOR	1	MTon/1...	0.285	0.285	0.285	0.285	0.285
SC_0	LNSORHI01	CRPSOR	1	MTon/1...	0.830	0.830	0.830	0.830	0.830
SC_0	LNDCOFU01	CRPCOF	1	MTon/1...	0.067	0.067	0.067	0.067	0.067
SC_0	LNDCOFH01	CRPCOF	1	MTon/1...	0.262	0.262	0.262	0.262	0.262
SC_0	LNDWHELR01	CRPWHE	1	MTon/1...	0.264	0.264	0.264	0.264	0.264
SC_0	LNDWHEHR01	CRPWHE	1	MTon/1...	0.568	0.568	0.568	0.568	0.568
SC_0	LNDWHELI01	CRPWHE	1	MTon/1...	0.273	0.273	0.273	0.273	0.273
SC_0	LNDWHEH01	CRPWHE	1	MTon/1...	0.646	0.646	0.646	0.646	0.646
SC_0	LNDCERLR01	CRPCER	1	MTon/1...	0.213	0.213	0.213	0.213	0.213
SC_0	LNDCERHR01	CRPCER	1	MTon/1...	0.487	0.487	0.487	0.487	0.487
SC_0	LNDCERLI01	CRPCER	1	MTon/1...	0.227	0.227	0.227	0.227	0.227
SC_0	LNDCERH01	CRPCER	1	MTon/1...	0.568	0.568	0.568	0.568	0.568
SC_0	LNDBRLR01	CRPBRL	1	MTon/1...	0.222	0.222	0.222	0.222	0.222
SC_0	LNDBRLHR01	CRPBRL	1	MTon/1...	0.529	0.529	0.529	0.529	0.529
SC_0	LNDBRLI01	CRPBRL	1	MTon/1...	0.272	0.272	0.272	0.272	0.272
SC_0	LNDBRLH01	CRPBRL	1	MTon/1...	0.597	0.597	0.597	0.597	0.597
SC_0	LNDMAILR01	CRPMZE	1	MTon/1...	0.409	0.409	0.409	0.409	0.409
SC_0	LNDMAHR01	CRPMZE	1	MTon/1...	0.906	0.906	0.906	0.906	0.906
SC_0	LNDMAILI01	CRPMZE	1	MTon/1...	0.473	0.473	0.473	0.473	0.473
SC_0	LNDMAHI01	CRPMZE	1	MTon/1...	1.234	1.234	1.234	1.234	1.234
SC_0	LNSORLR01	CRPSOR	2	MTon/1...	0.253	0.253	0.253	0.253	0.253
SC_0	LNSORHR01	CRPSOR	2	MTon/1...	0.646	0.646	0.646	0.646	0.646
SC_0	LNSORLI01	CRPSOR	2	MTon/1...	0.285	0.285	0.285	0.285	0.285
SC_0	LNSORHI01	CRPSOR	2	MTon/1...	0.830	0.830	0.830	0.830	0.830
SC_0	LNDCOFU01	CRPCOF	2	MTon/1...	0.067	0.067	0.067	0.067	0.067
SC_0	LNDCOFH01	CRPCOF	2	MTon/1...	0.262	0.262	0.262	0.262	0.262
SC_0	LNDWHELR01	CRPWHE	2	MTon/1...	0.264	0.264	0.264	0.264	0.264
SC_0	LNDWHEHR01	CRPWHE	2	MTon/1...	0.568	0.568	0.568	0.568	0.568
SC_0	LNDWHELI01	CRPWHE	2	MTon/1...	0.273	0.273	0.273	0.273	0.273
SC_0	LNDWHEH01	CRPWHE	2	MTon/1...	0.646	0.646	0.646	0.646	0.646
SC_0	LNDCERLR01	CRPCER	2	MTon/1...	0.213	0.213	0.213	0.213	0.213
SC_0	LNDCERHR01	CRPCER	2	MTon/1...	0.487	0.487	0.487	0.487	0.487
SC_0	LNDCERLI01	CRPCER	2	MTon/1...	0.227	0.227	0.227	0.227	0.227
SC_0	LNDCERH01	CRPCER	2	MTon/1...	0.568	0.568	0.568	0.568	0.568
SC_0	LNDBRLR01	CRPBRL	2	MTon/1...	0.222	0.222	0.222	0.222	0.222

Figure 10 Crop yield - data entry

The figure has been created using the MUIO v.5.3 user interface

12 Crop demand

Current CLEWs models input crop demand as "AccumulatedAnnualDemand". This demand represents the total demand in one year and is not affected by the model time resolution. In order to ensure consistency across seasons, we need to exploit the model's linear correlation between demand and supply. The demand will therefore have to be split across the model's year split.

We use the parameter "**Specified Annual Demand**" which is the total specified demand for the year, linked to a specific 'time of use' during the year. The way of "linking" it to the time in OSeMOSYS is done with the "**Specified Demand Profile**" parameter which is the annual fraction of commodity demand that is required in each time slice. For crops we will input **the same value as the year-split**.

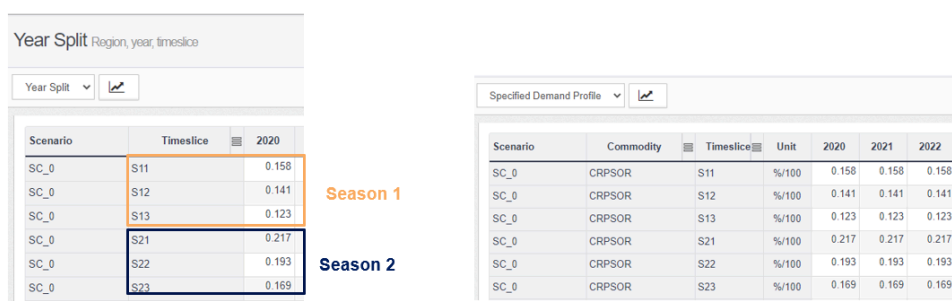


Figure 11 The specified demand profile for crop demand

*The figure has been created using **MUIO v.5.3** user interface*

- 13 Because of the importance in keeping the consistency across the seasons, **all the calibration is done using only the activity instead of the capacity**. The reference year is characterized by a lower and upper annual activity limit (the upper limit and the max capacity can be 1% higher than the lower to avoid infeasibilities), and by a maximum capacity equal to the upper activity limit in order to make sure that the reference year respects the land-use calibration.
- 14 Moreover, unlike other CLEWs model, all the croplands will have 1 year as operational life and no capital costs. The reason is because it is important to ensure consistency between capacity and activity. For instance, if a land technology has 15 years of operational life, the installed capacity will last for 15 years. However, depending on the optimization process, the technology can either produce (activity = capacity), or it can

be substituted by another technology that is replacing the former one (there is new capacity from another technology and therefore the former might face a decrease in the activity).

- 15 After the first year, the model is calibrated using the parameters *Technology Activity Decrease By Mode Limit* and *Technology Activity Increase By Mode Limit*. **Note that it is important to assign the same values for both modes of operations.**
- 16 Finally, each technology is characterized by Fixed and Variable costs. Note that **also the Variable costs have to be assigned for both modes**. The capital costs are **zero** because we set 1 as Operational Life, assuming that the cost of buying land does not vary across crop types.
- 17 **Model set-up for techno-economic parameter.**

1	Parameter	Technol ogy	Mode of operation	Value
2	Total Annual Max Capacity	LNDCRP	-	Calibrated value only for the reference year
3	Total Technolog y Annual Activity Lower Limit	LNDCRP	-	Calibrated value only for the reference year
4	Total Technolog y Annual Activity Upper Limit	LNDCRP	-	Calibrated value only for the reference year
5	Technolog y Activity Decrease By Mode Limit	LNDCRP	1	Same value as mode 2
6	Technolog y Activity Decrease	LNDCRP	2	Same value as mode 1

	<i>By Mode Limit</i>			
7	<i>Technology Activity Increase By Mode Limit</i>	LNDCRP	1	Same value as mode 2
8	<i>Technology Activity Increase By Mode Limit</i>	LNDCRP	2	Same value as mode 1
9	<i>Fixed Cost</i>	LNDCRP	-	
10	<i>Variable Cost</i>	LNDCRP	1	Same value as mode 2
11	<i>Variable Cost</i>	LNDCRP	2	Same value as mode 1

Figure 12 Adding techno-economic constraints.

18 Check that you have made no mistakes.

This is an example of how the harvested area should look like across the seasons (1 and 2). The figure has been created using the MUIO v.5.3 user interface, and displays the results of **Rate Of Activity** filtered by croplands, and by modes of operation (Mo Id) in the rows as shown in the figure below.

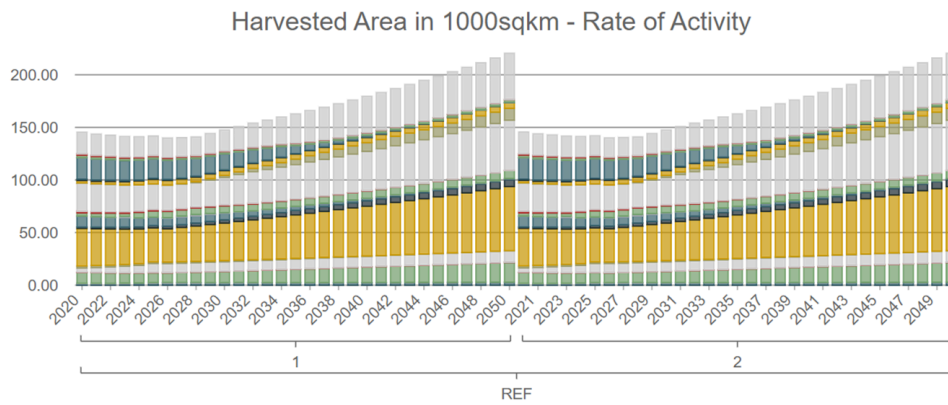


Figure 13 Consistency across seasons - result example done with MUIO v5.3

The figure has been created using MUIO v.5.3 user interface

Step 3 - Modelling water seasonality

19

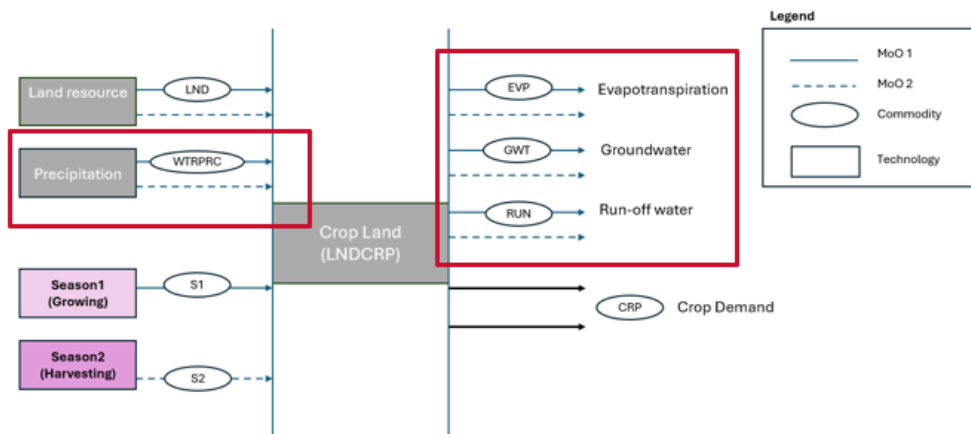


Figure 14 Schematic reference system of the seasonal water balance represented in OSeMOSYS.

Focus on the water balance

20 Enter the input activity ratio for crops (precipitation)

Also in this case, remember to keep the same consistency across modes and season. Mode 1 will have to represent the precipitation of season 1 and mode 2 of season 2.5

Commodity	Mode of operation	Value
WTRPRC	1	Precipitation associated to season 1
WTRPRC	2	Precipitation associated to season 2

Figure 15 Input activity ratio for each crop (precipitation).

21 Enter the water output (evapotranspiration, groundwater, run-off water)

Commodity	Mode of operation	Value
EVP	1	Evapotranspiration associated to season 1
EVP	2	Evapotranspiration associated to season 2
GWT	1	Groundwater recharge associated to season 1
GWT	2	Groundwater recharge associated to season 2
RUN	1	Run-off water associated to season 1
RUN	2	Run-off water associated to season 2

Figure 16 Output activity ratio for water.

Analyzing the results

22 The water seasonality

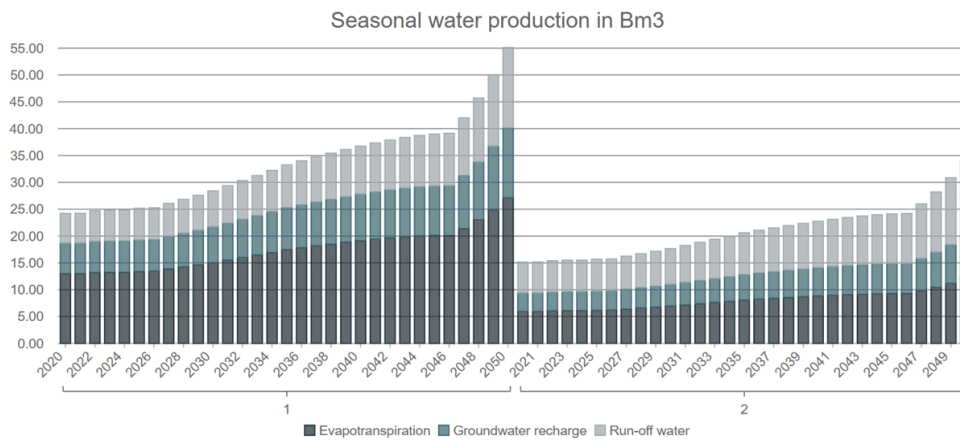


Figure 17 *Evapotranspiration, Groundwater and run-off water seasonality in Bm³*

The figure represents on the vertical axis the Bm³ of renewable groundwater and run-off water produced by the harvested area, while the horizontal axis represents its production through the modelled years. The horizontal axis is further divided into two sub-sections namely 1 and 2 which represents the behaviour of the two modes of operation: mode 1 and mode 2 (representing respectively growing and harvesting season).

*The figure has been created using the **MUIO v.5.3** user interface*

23 Analysis

It is possible to observe differences in run-off and groundwater recharge across seasons. These differences depend on the overall seasonal water balance. For instance, run-off increases in Season 2 because this period corresponds to the crop-growth stage during which plants require less water. As a result, evapotranspiration decreases, leading to an increase in runoff.

On the other hand, groundwater recharge decreases in Season 2 because it corresponds to the dry season. The reduction in precipitation during this period negatively affects groundwater recharge.

Acknowledgements

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