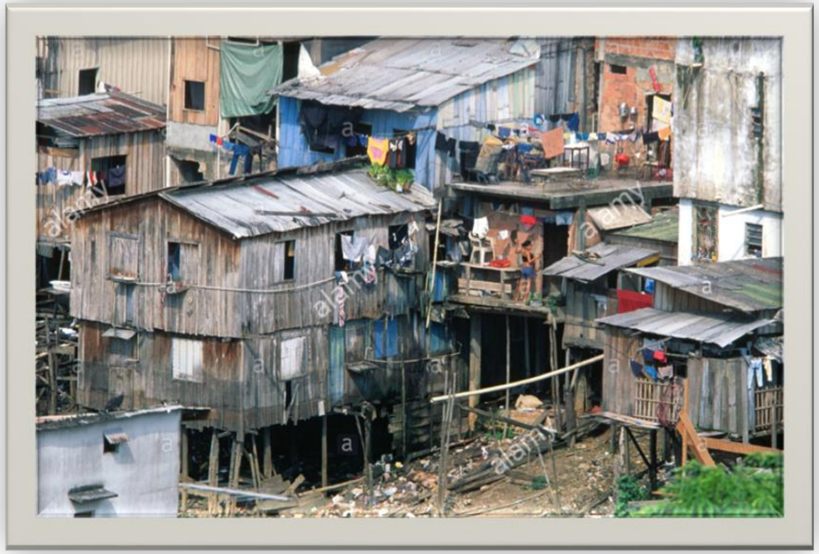
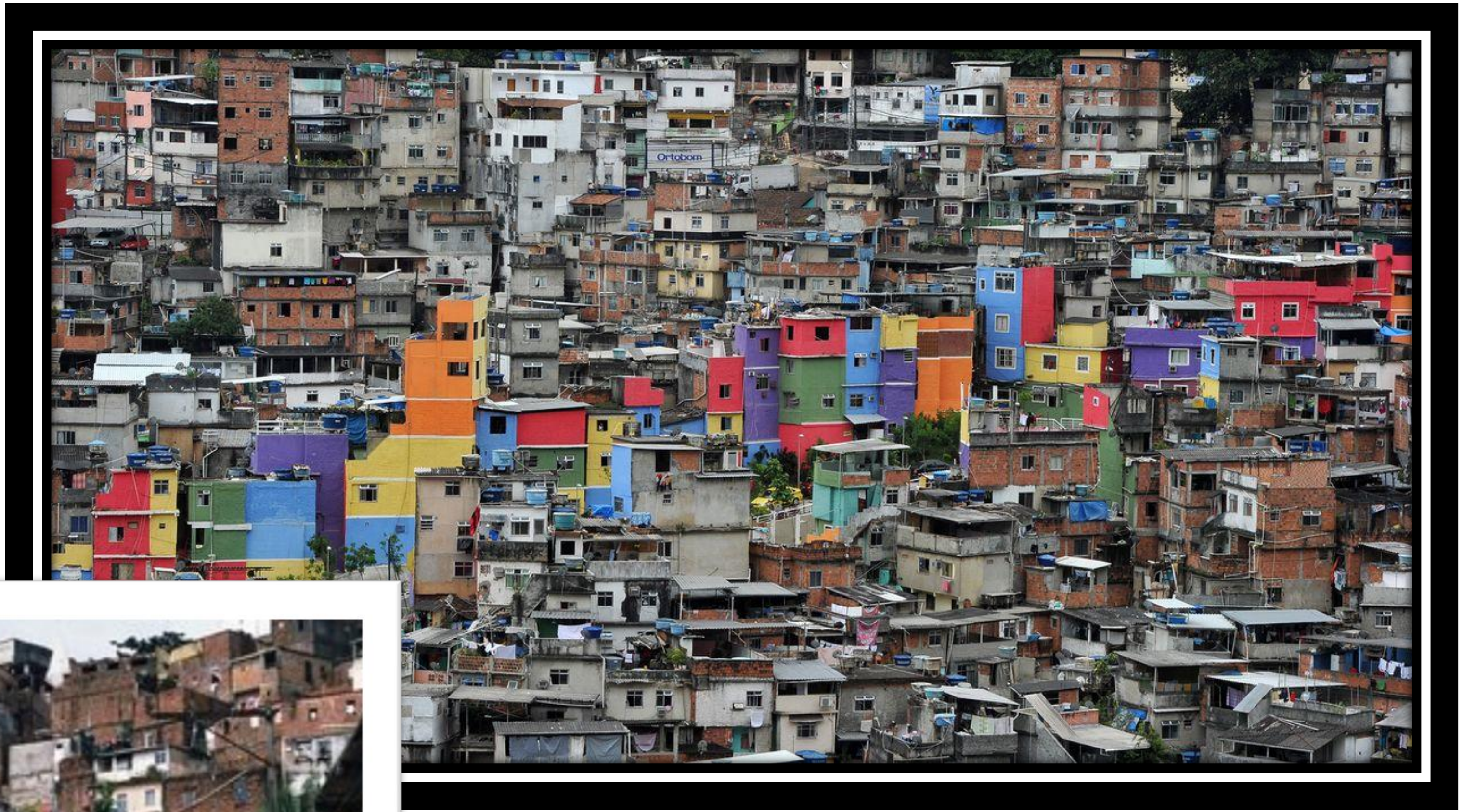
Dynamic system modeling applied to Water-Energy-Food (WEF) nexus in an urban environment

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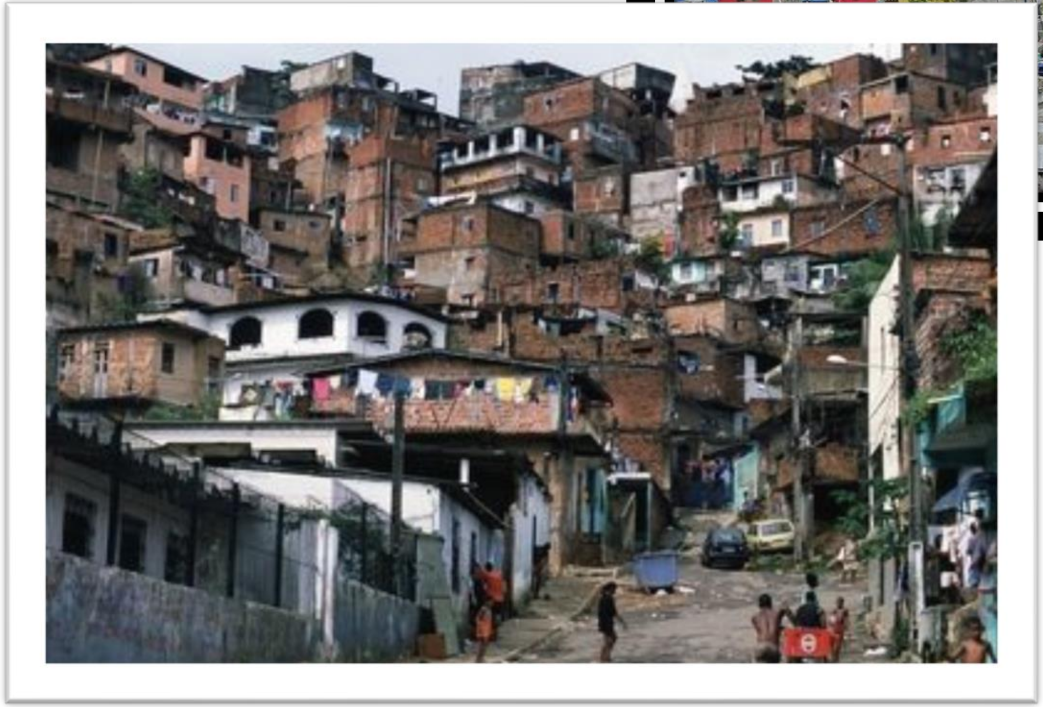
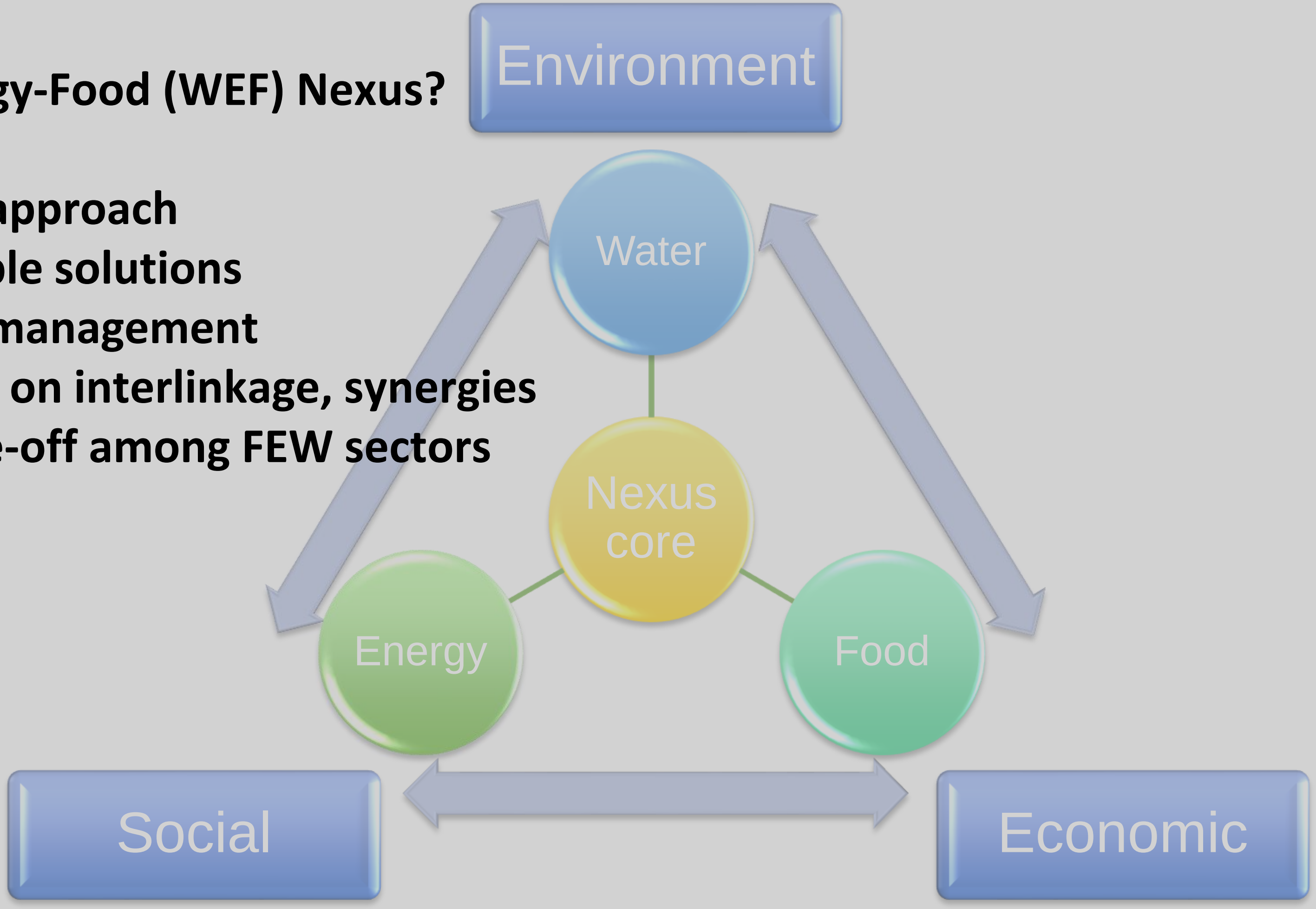
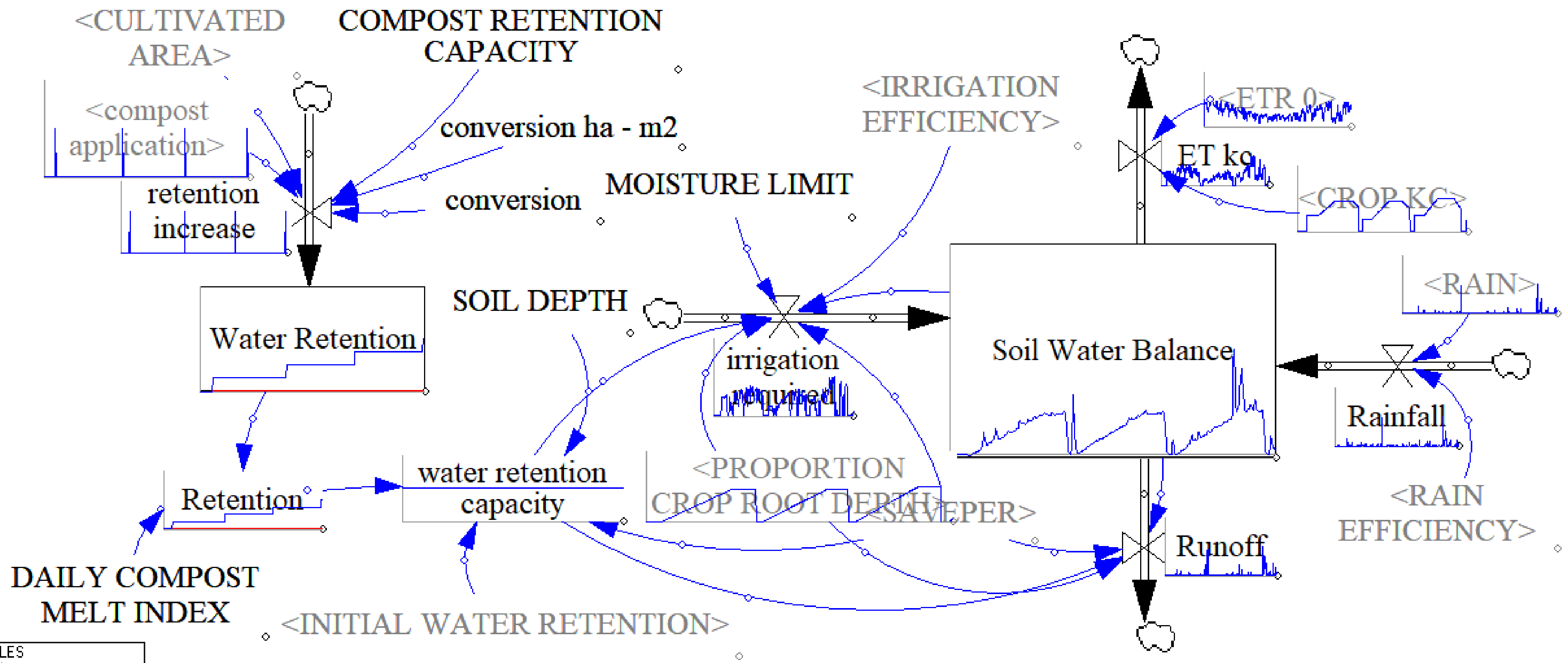


Water-Energy-Food (WEF) Nexus?

- **Systems approach**
- **Sustainable solutions**
- **Efficient management**
- **Emphasis on interlinkage, synergies and trade-off among FEW sectors**





1-INPUT VARIABLES
2-AMONIA INDEX
3- HOME GENERATION
4-URINE STOCK
5-SOIL WATER BALANCE
6-IRRIGATION
7-COMPOST
8-YIELD AND VEGETABLE STOCK
9-BALANCES
10-ENERGY

Name in CAPITAL letters: **Parameters**
Name in lower case : **Variables**
Name in grey : **Shadow terms, the terms that come from the other loop**

Objectives

- ENLARGE project objective: to assess the potential of the circular economy in urban environment
- Primary objective of the project : to create a model to evaluate different configurations to answer the principle question of recycling and reuse
- Principle question: Is there any lack of resources to achieve the amount of production required to feed the community?
- Modeling objectives:
    - ✓ To reproduce the existing framework: flow and stocks dynamic system
    - ✓ To grow enough crops to feed a community
    - ✓ Recycling its gray water, urine, harvested precipitation and organic wastes
    - ✓ Test on Brazilian case studies
- Objective of the future thesis (Ecofilae-INRAE) : Improving the flexibility, interactivity and scalability of the model, which is required by the complex nature of the FEW nexus in various case study.

Information on the approach

Scale

- Small community
- One-year duration
- Daily time-step

Interdependency

Food – Water – Energy
+ (Climate)

Simulation method

- System dynamics modeling (on Vensim)
- A model based on causal mechanism
- Aggregation of individual loops

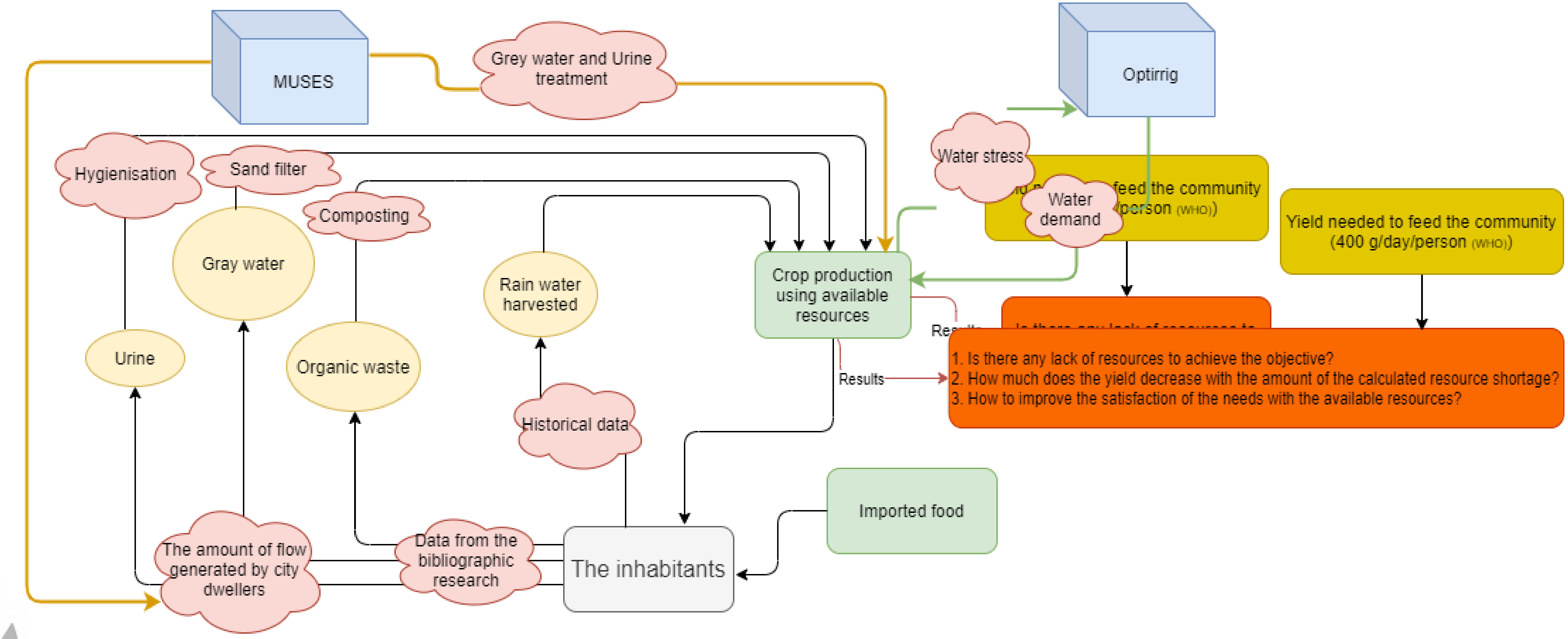
Over the past year...

- Test the application of the model in 3 study cases in Brazil (with a sharp climate contrast) considering two different resource management policies.
- Translate the model under Vensim into Python in order to couple the model with MUSES (effluent management) and Optirrig (crop and irrigation).

The model…

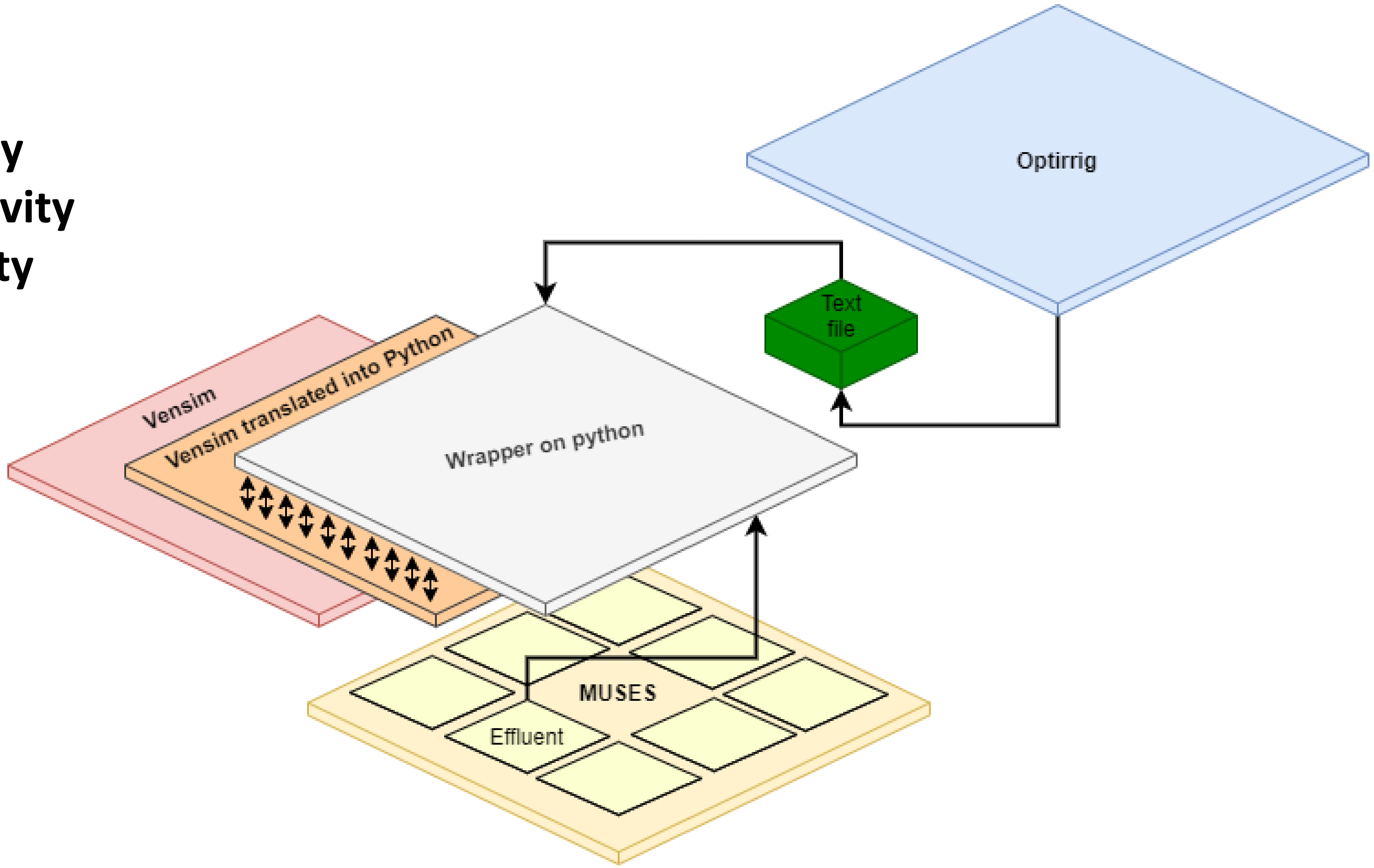
- Developed by Prof Gisele Chaves & Antoine Leguillou
- First extended and validated by David Galibourg

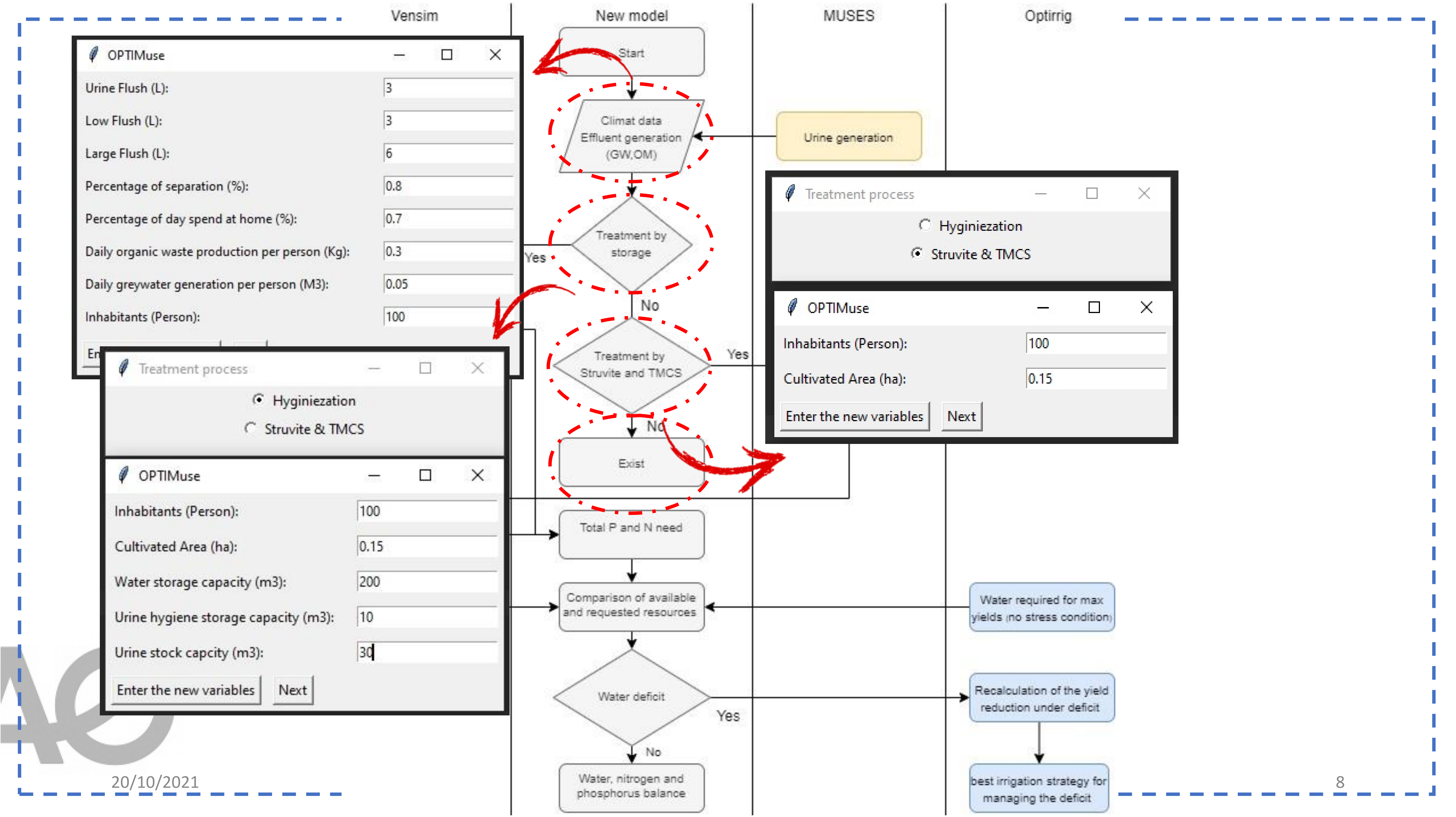
Initial and final model construction



Computer science behind

- **Flexibility**
- **Interactivity**
- **Scalability**

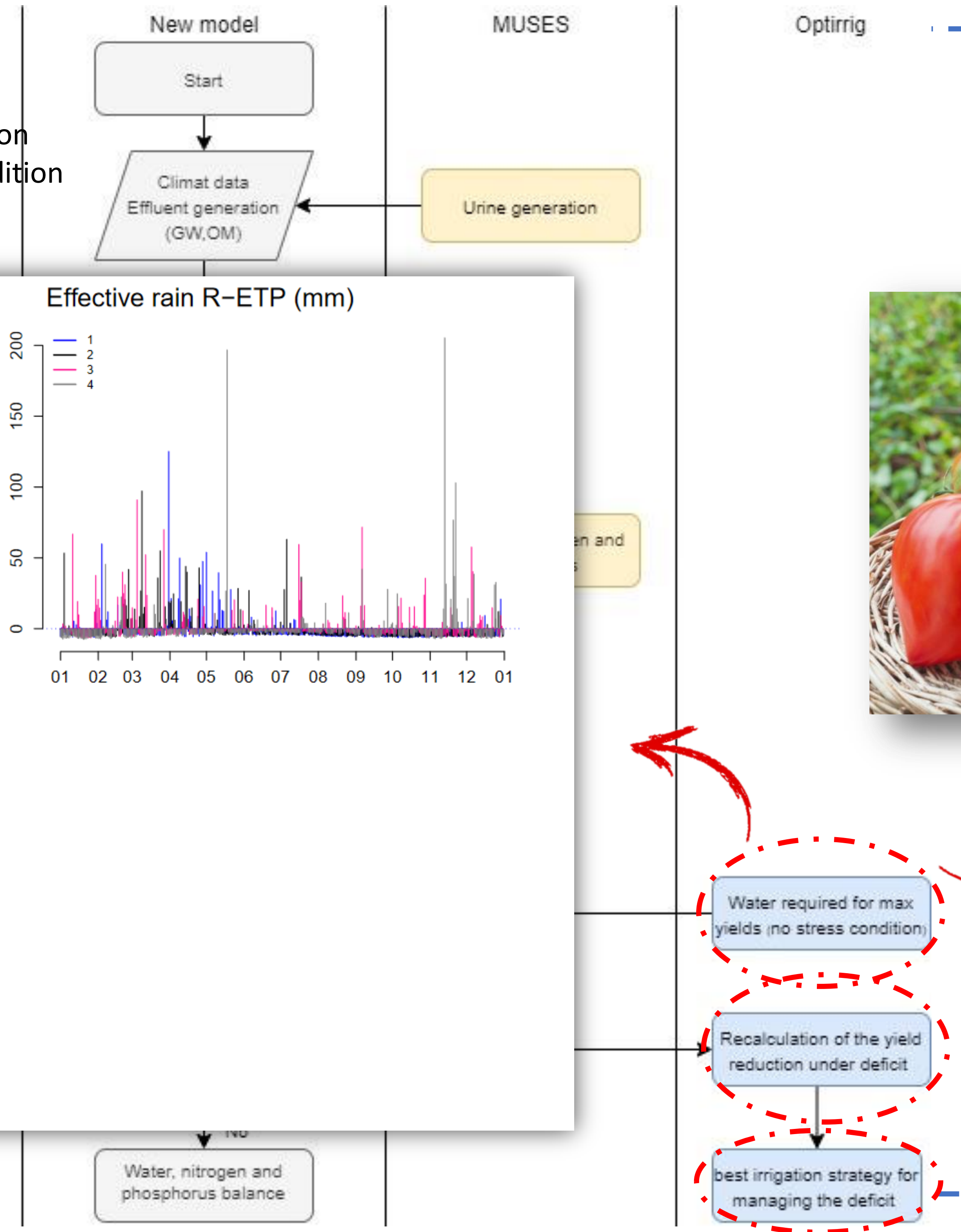


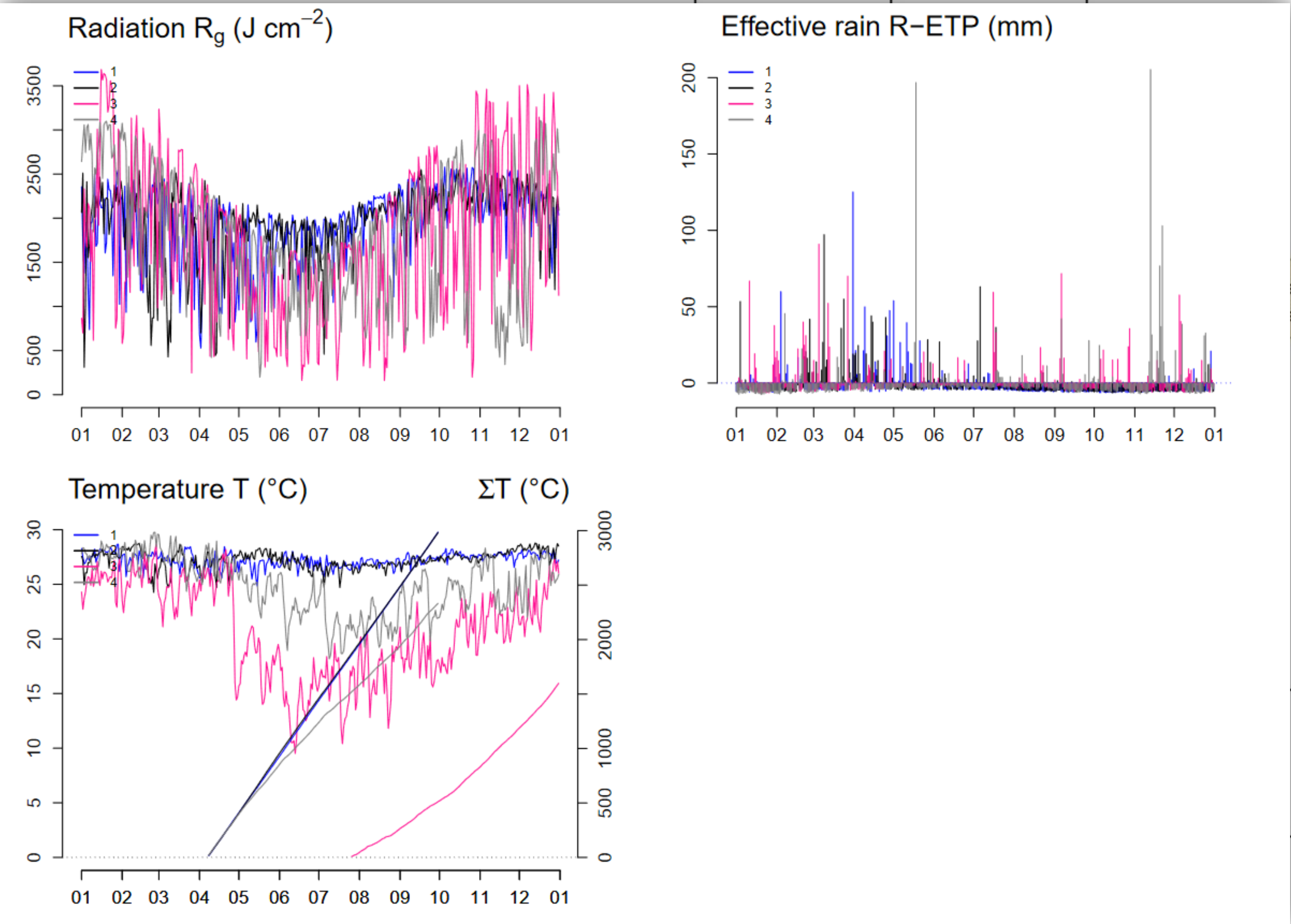


Vensim
New model
MUSES
Optirrig
OPTIMuse
Urine Flush (L): 3
Low Flush (L): 3
Large Flush (L): 6
Percentage of separation (%): 0.8
Percentage of day spend at home (%): 0.7
Daily organic waste production per person (Kg): 0.3
Daily greywater generation per person (M3): 0.05
Inhabitants (Person): 100
Treatment process
Hyginiezation
Struvite & TMCS
OPTIMuse
Inhabitants (Person): 100
Cultivated Area (ha): 0.15
Water storage capacity (m3): 200
Urine hygiene storage capacity (m3): 10
Urine stock capcity (m3): 30
Enter the new variables
Next
Start
Climat data
Effluent generation
(GW,OM)
Urine generation
Treatment by storage
Yes
No
Treatment by Struvite and TMCS
Yes
No
Exist
Treatment process
Hyginiezation
Struvite & TMCS
OPTIMuse
Inhabitants (Person): 100
Cultivated Area (ha): 0.15
Enter the new variables
Next
Total P and N need
Comparison of available and requested resources
Water required for max yields (no stress condition)
Water deficit
Yes
No
Recalculation of the yield reduction under deficit
best irrigation strategy for managing the deficit
Water, nitrogen and phosphorus balance

(1)Blue : Fortaleza – Dry climate condition
(2)Black: Fortaleza – Average climate condition
(3)Pink: Florianopolis – Average climate condition
(4)Grey: Vitoria – Average climate condition

Source of data: INMET Brazilian climate site





Results

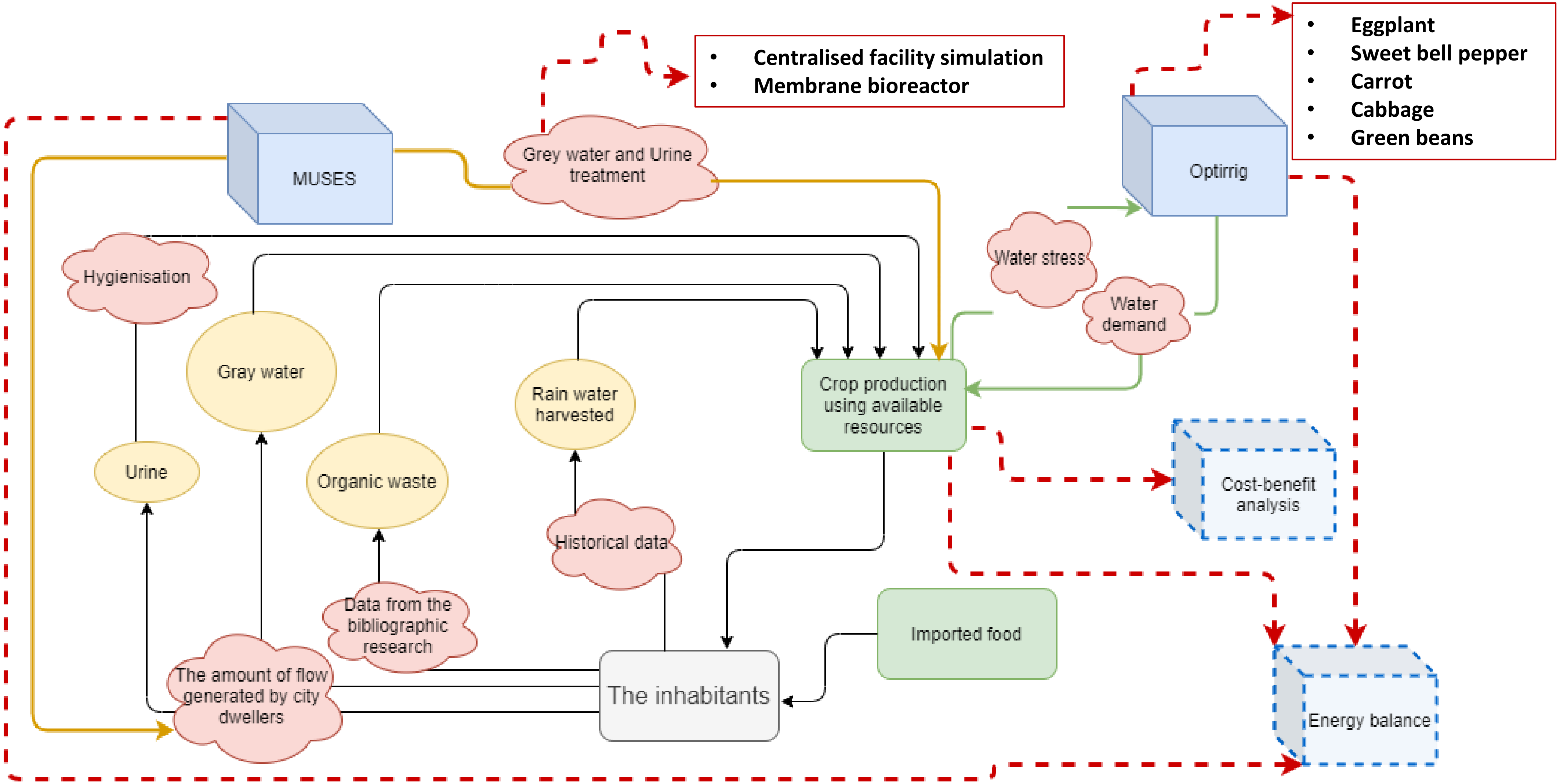
	Vitoria		**Florianópolis**		**Fortaleza**			
Projet	**Agricultores Urbanos**		**Baldinhos Revolution**					
Flush scenario	With toilet flush	Without toilet flush	With toilet flush	Without toilet flush	With toilet flush		Without toilet flush	
Projet	**Average climate**		**Average climate**		Average climate	Dry climate	Average climate	Dry climate
Crop water requirements for maximum productivity ($m3$)	420	420	216	216	690	1650	690	1650
Maximum production ($T/ha/year$)	22,182	22,182	30,475	30,475	15,94	13,46	15,94	13,46
Cultivated area to feed a community of 100 people (ha)*	0.7	0.7	0.48	0.48	0.92	1.1	0.92	1.1
Applied irrigation water (m^3)	367	322	216	216	627	613	406	424
Water Balance (m^3)	-53	-98	0	0	-62	-1036	-284	-1226
from greywater (%)	53%	65.8%	7%	65.2%	51.3%	50.4%	51%	58.7%
from Rainfall (%)	27%	32.9%	10%	34.7%	35.7%	36%	47.6%	41.2%
from yellowWater (%)	20%	1.3%	81%	3.6%	13%	13.6%	1.4%	1.3%
Overflow (m^3)	1547	1487	1896	1715	1215	1030	1165	1037
Production shortfall	-	-	0	0	-	-	-	-

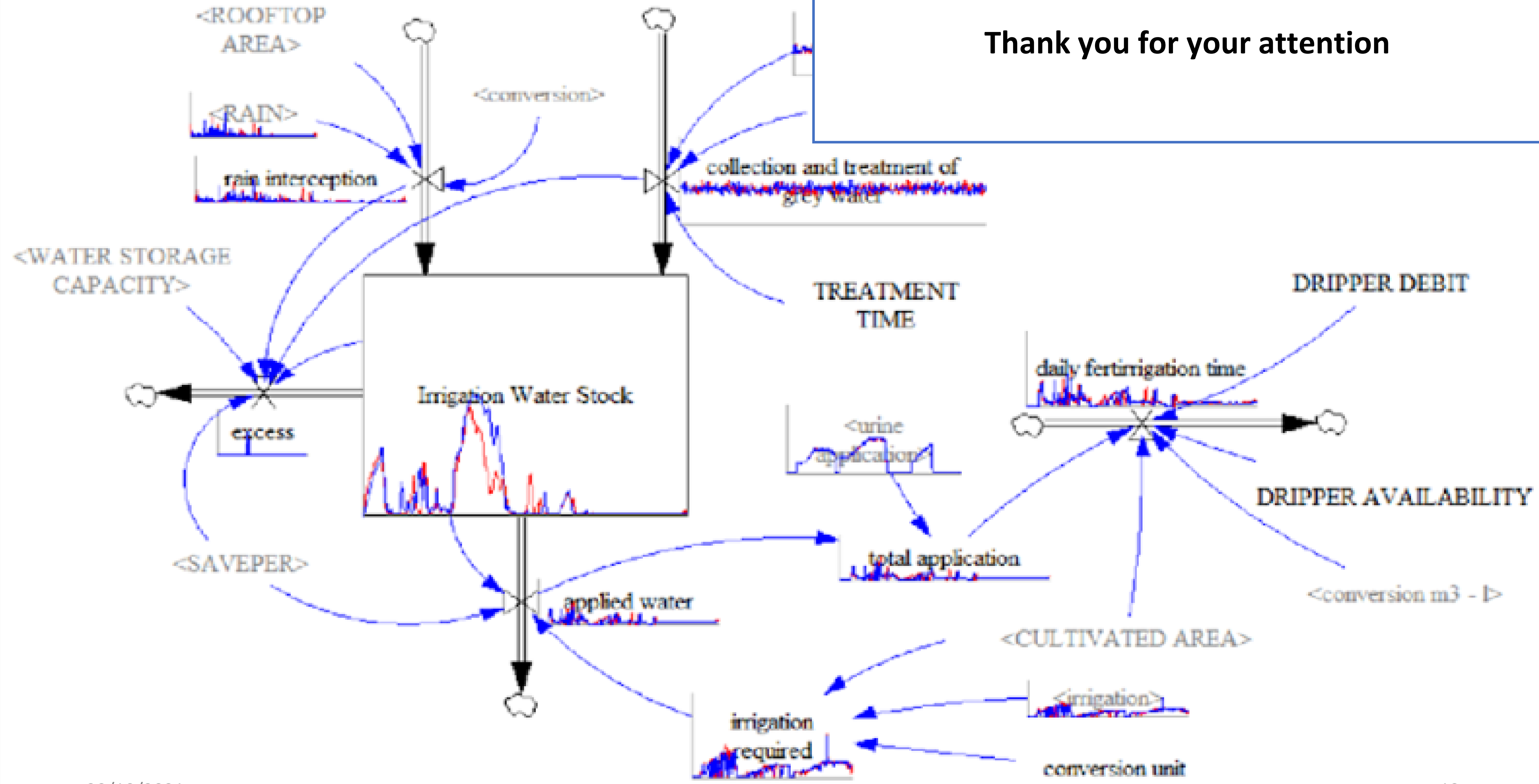
Table 3: The results of the first scenario simulation within the Optirrig/OptiMuses linkage

PhD propositions

The general idea is to create a core that will do the super-simple, free access, basic scenario (we can even consider it as a learning tool to raise awareness among the different stakeholder groups) and then a more detailed, data-driven second level loop to do advanced studies on the project.

Enhancing crop data library





Thank you for your attention

Eventual question

Structure analysis

Validity of the model

Optirrig irrigation functionality

Results

The limits of the approach

The missions during my CDD

The missions during my CDD

Define a district with characteristic of Favelas

Consider nutrients in grey water

Tight coupling with a simplified version of Optirrig.

The calculation of the production shortfall

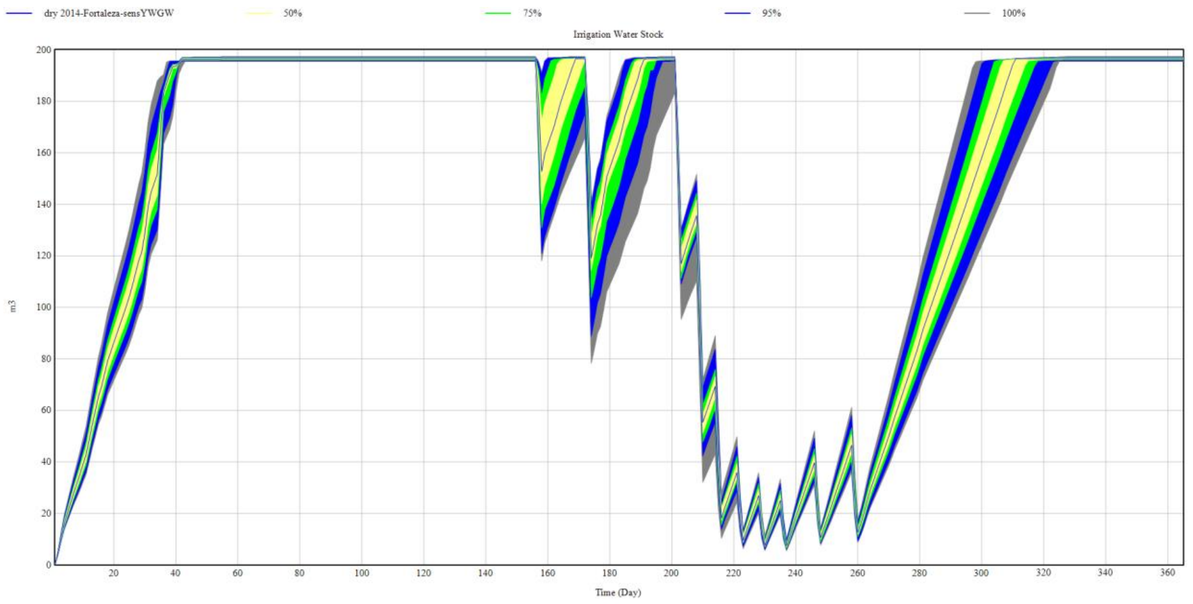
Validity test on integration-level

Structure analysis

- Structure verification test
- Boundary adequacy test
- Parameter verification test
- Dimensional consistency test
- Extreme conditions test

Behavior analysis

Label of the input factors	Probability distribution	Unit	Minimum	Mean	Maximum	Standard deviation
Rain - Dry scenario	Normal	m^3/day	0	2.92	128.4	10.12
Rain- Average scenario	Normal	m^3/day	0	3.51	98.4	10.2
Yellow water production	Normal	$m^3/pers/day$	0.00085	0.0047	0.00865	0.0054
Grey water production	Normal	$m^3/pers/day$	0.032	0.05	0.073	0.028991



Optirrig irrigation functionality

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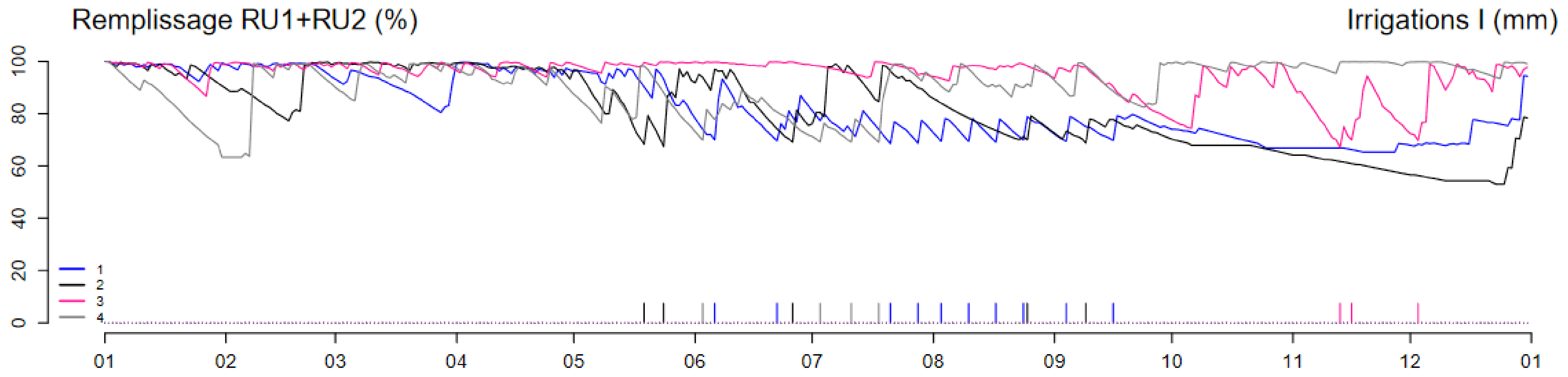

Limits of the approach

- There is no model that is totally fixed to our objective
- There is always a detail that may be forgotten as we are not the model developer, therefore, it required more attentions
- Having the right of the source code of the selected models
- Model updating
- Cooperate with different teams within certain limits