ISINAPSYS
[Organización que Aprende]®

Sahel Learning Lab.

Supporting Materials

Published for:

The 32nd International Conference of the System Dynamics Society, Delft, Netherlands

July 20 – July 24, 2014

Good Governance in a Complex World

AUTHORS

Pedro Dagoberto Almaguer Prado	pedrodago@gmail.com	Author
Beatriz Eugenia Navarro Vázquez	bety.5505@gmail.com	Collaborator
Ruth Raquel Almaguer Navarro	ruth_ran@hotmail.com	Design
Ramiro Luis Almaguer Navarro	rmalmaguer@gmail.com	Modeling
Pedro Dagoberto Almaguer Navarro	pan.dago82@gmail.com	Collaborator

March 12, 2014

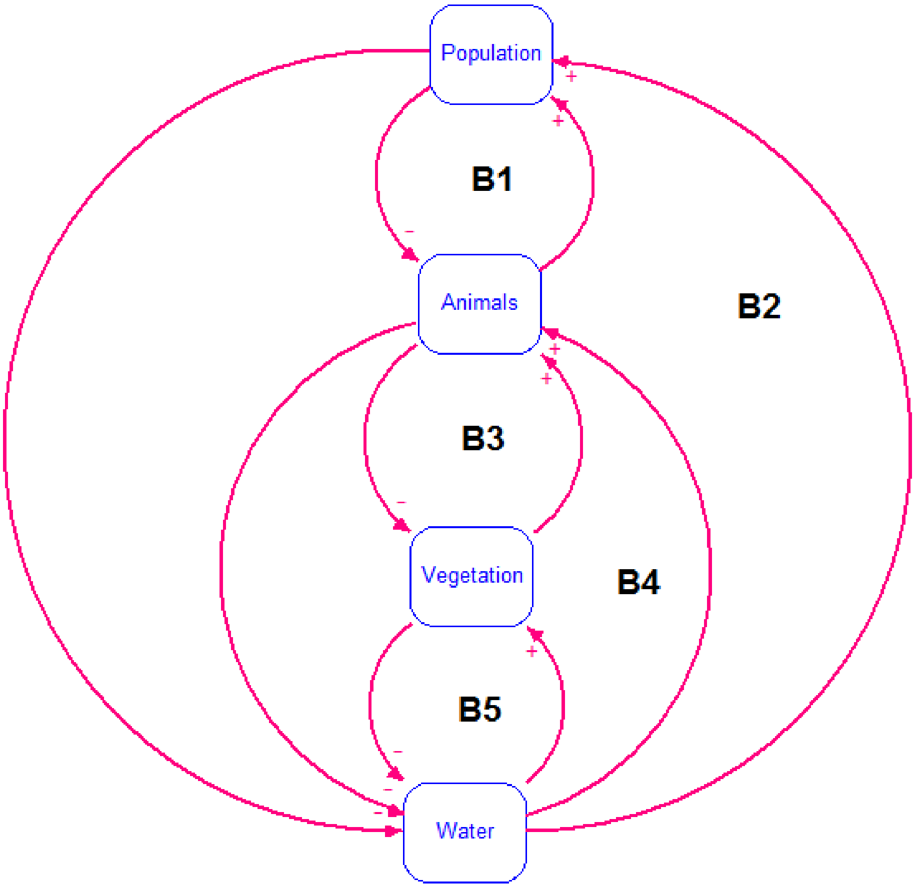
Objective:

In this occasion we'll examine a fragil and desert ecosystem called the SAHEL at the North of Africa, under Sahara's desert. Where in the recent 50 years an unusual drought has caused famine, poverty and death in the population. Even though there have been well-intentioned efforts from global organizations as the UN, to support, with strategies for change, the improvement of the quality and life expectancy for people, very little has been achieved and the results have collapsed in a few years. Any change in any part of the system, wether applied to pumping waters from wells, health campaigns for population, the genetic improvement of animals to increase the food production, or to improve the field productivity, almost immediately affects on another part of the system and the cause-effect cycles of negative balance settle the system, where is very complex to overcome the constrains imposed by the environment. In this activity, the student will learn to model complex ecosystems, where any improvement strategy to implement in one of its parts, affects all simultaneously. As their main goal, they'll look for achieving a long-term **sustainability** in the ecosystem, where the economic, social and ecological goes together.

Keywords - Learning Labs, Social Science, Environment, Simulation, **sustainability**

Contents

Sahel – System Modules



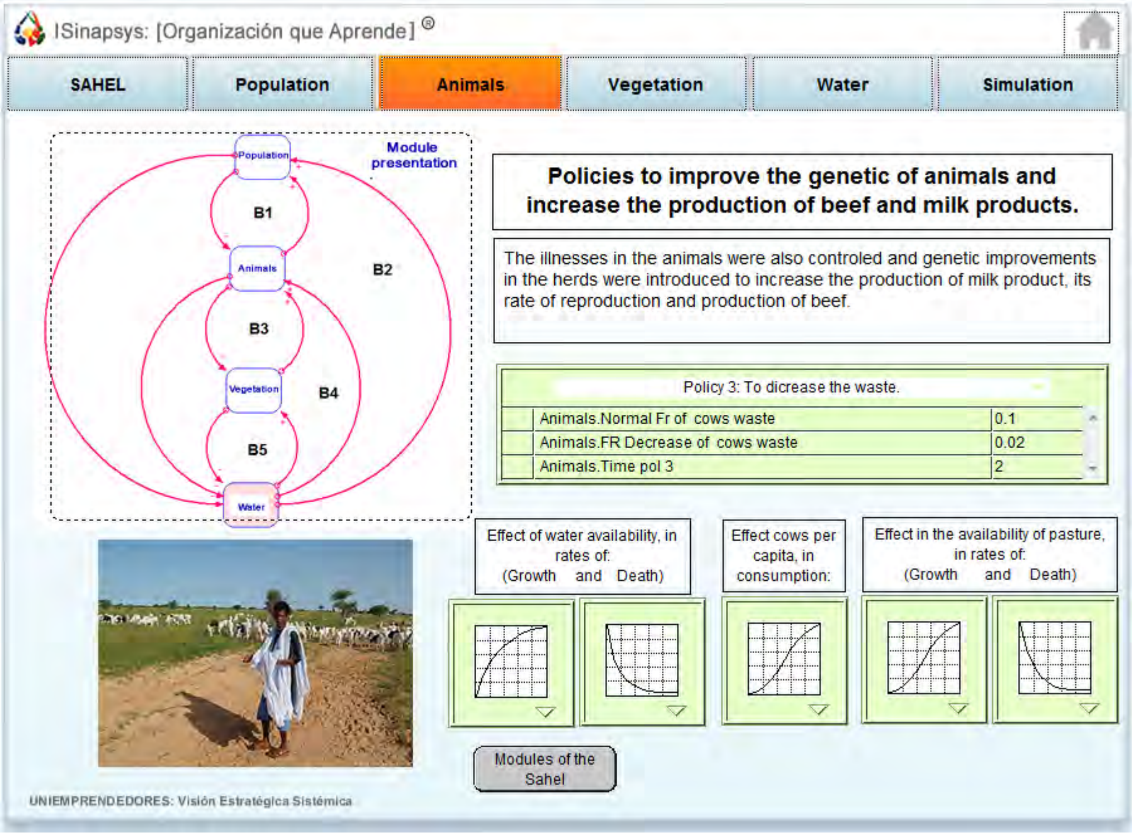
Development model step by step.

Modeling a sustainable lifestyle.

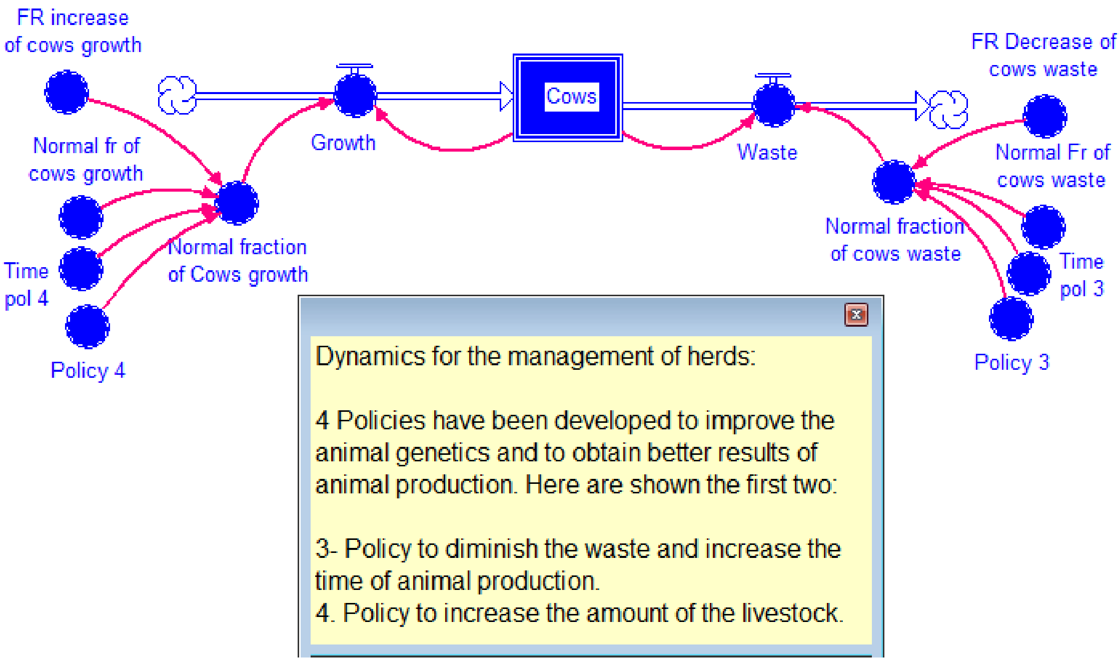
In this occasion, we've developed a complete bussiness game to solve the Sael's Model, where step by step we'll explain the pieces involved:

1. Its cause-effect cycles that links its modules.
2. Each module is in detail explained how was modeled.
3. There have been created 11 new policies that affect the behavior of each module and all the system in consequence, among wich are the following:
    a. Policies to improve the quality and life expectancy of the population.
    b. Genetic improvement of the animal herds to increase their reproduction, their milk products and their meat.
    c. New policies in the management of pastures to improve their productivity and its regeneration time.
    d. Policies and procedures to improve the use and explotation of water.
4. Each data involved (3), can be modified to visualize its impact on time for each decision taken.
5. Variables that calculate the percentage of pasture, water and all the system supplies have been created for the modules that run the vegetation and water.
6. Through the simulation of the complete system, the impact our decisions have on time can be seen, each of the policies can be implemented separately or combined.

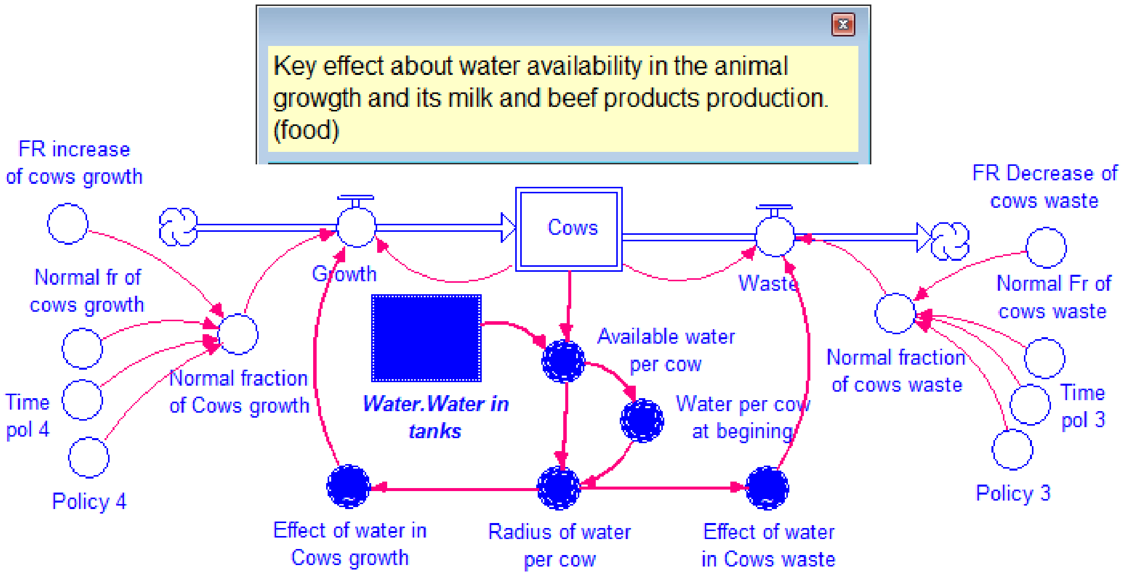
Module for the animals.



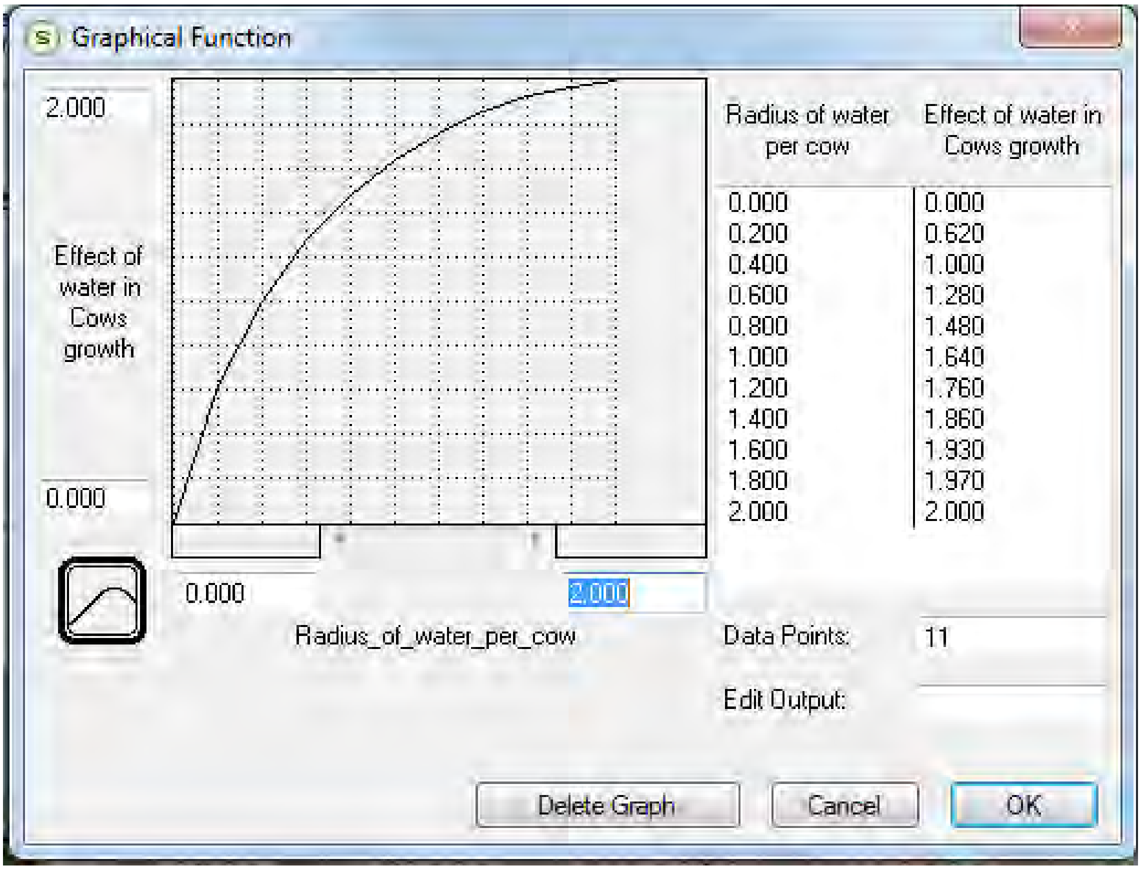
Dynamics for the management of the herds of animals.



Effect of water availability in the growth of herds.

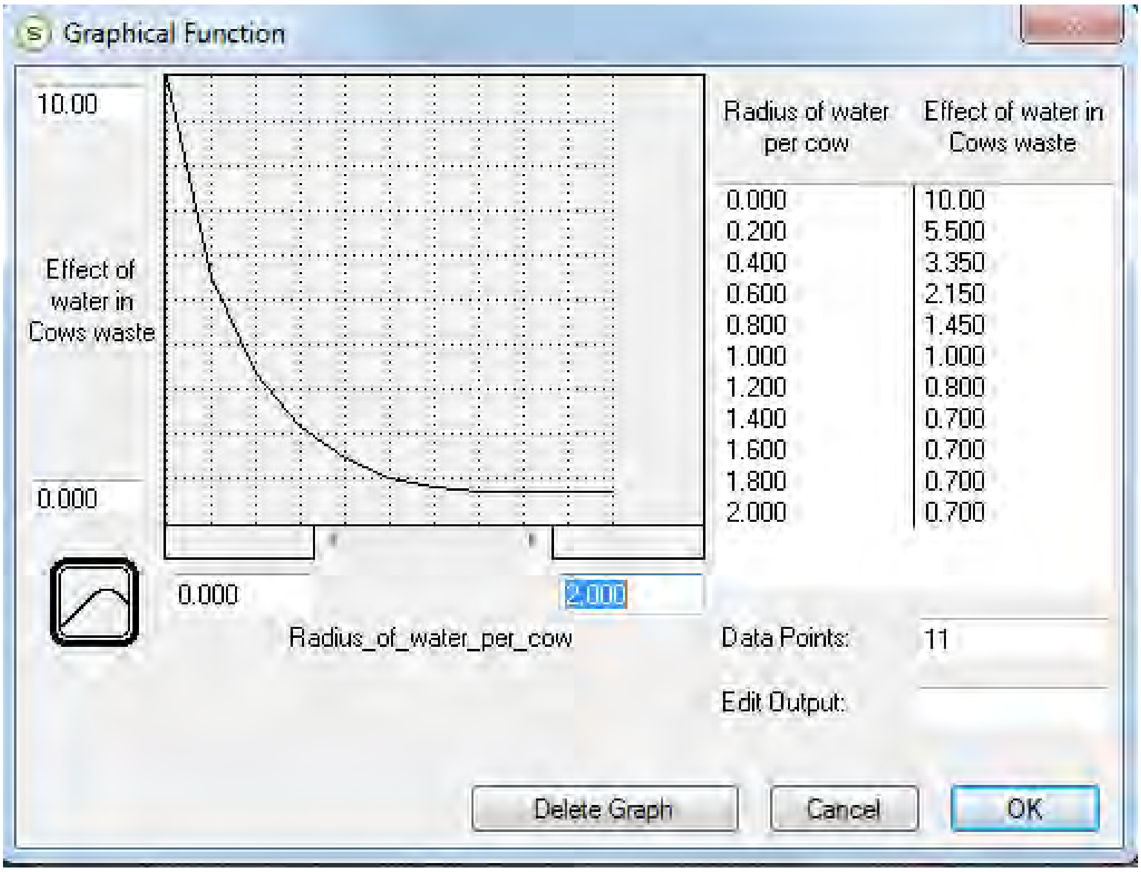


Graph of the effect of water availability in the growht of cows.

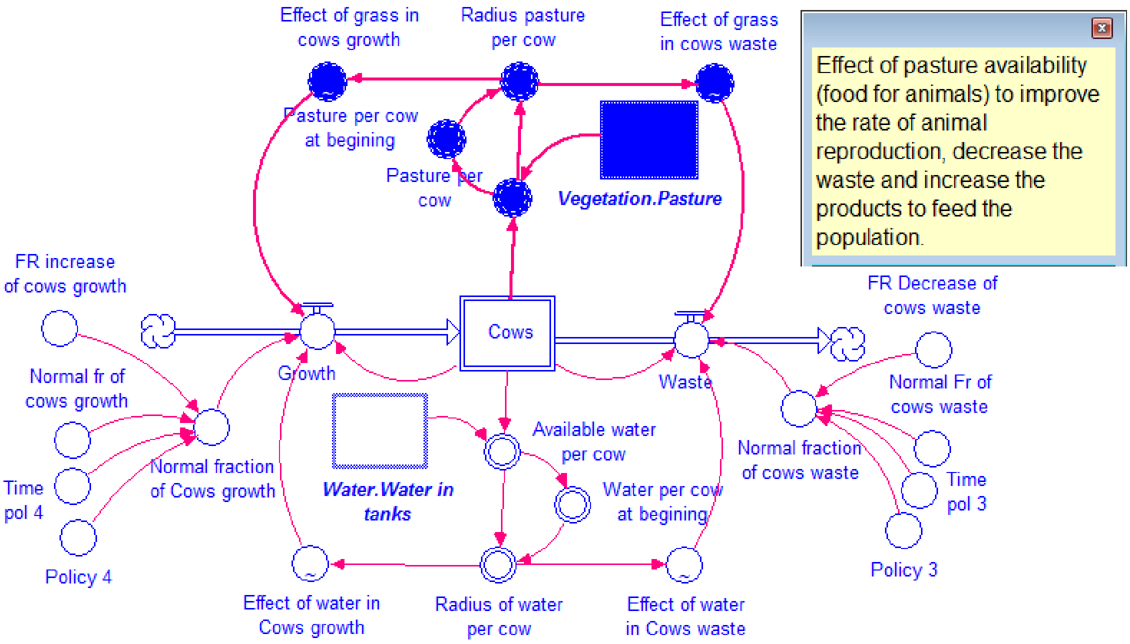


When the radious of water per cow is greater than 1, the cows' normal fraction of growth increases, if it is less than 1, the opposite occurs.

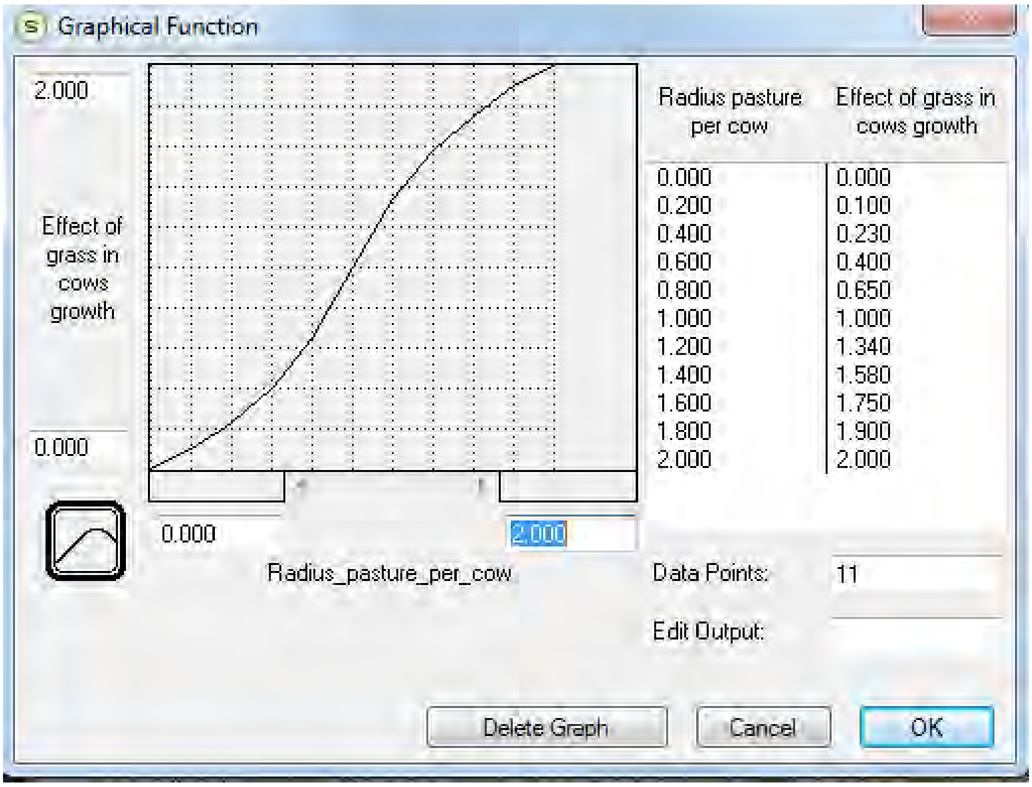
Graph of the effect of water availability in the production of animal wastes.



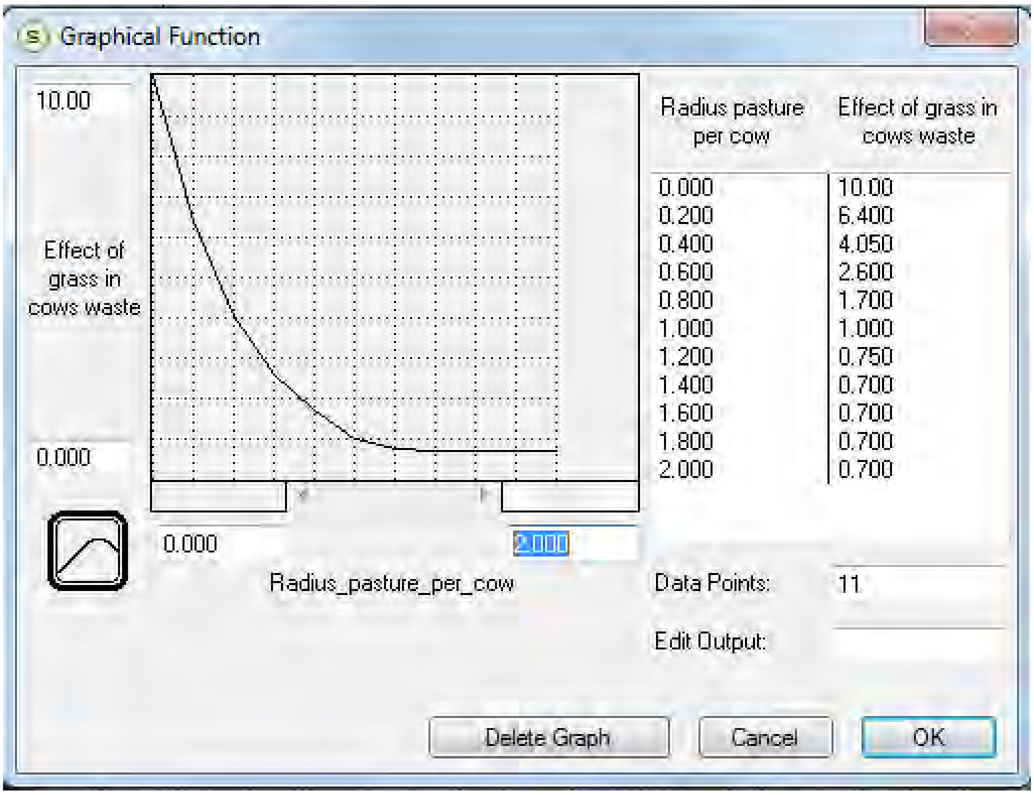
Effect of the availability of pasture in the animal growth.



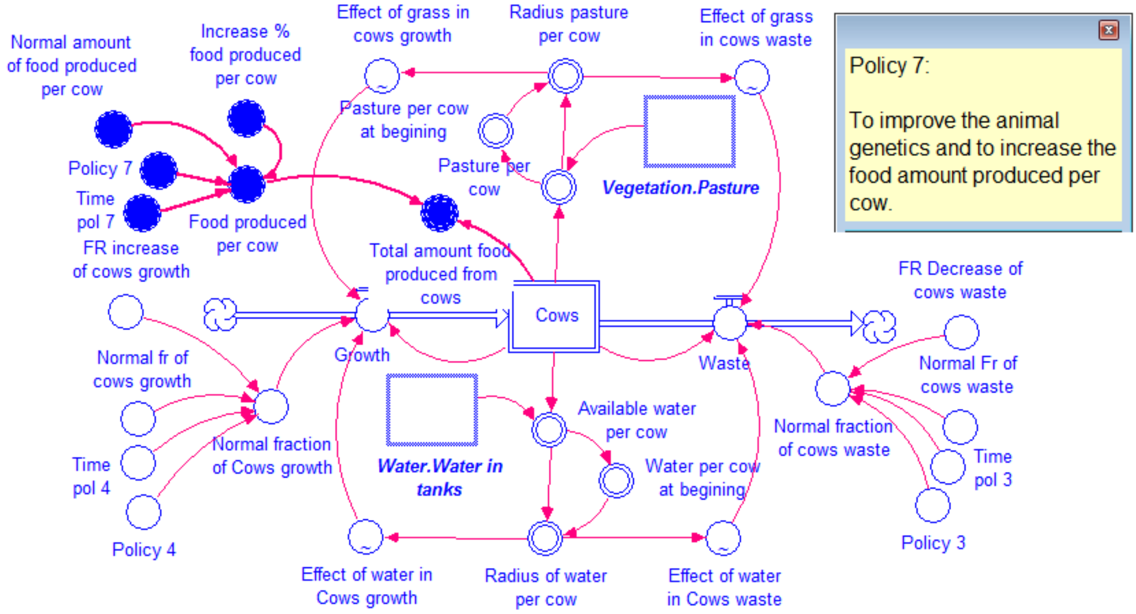
Graph of the effect in the availability of pasture in the cows growth.



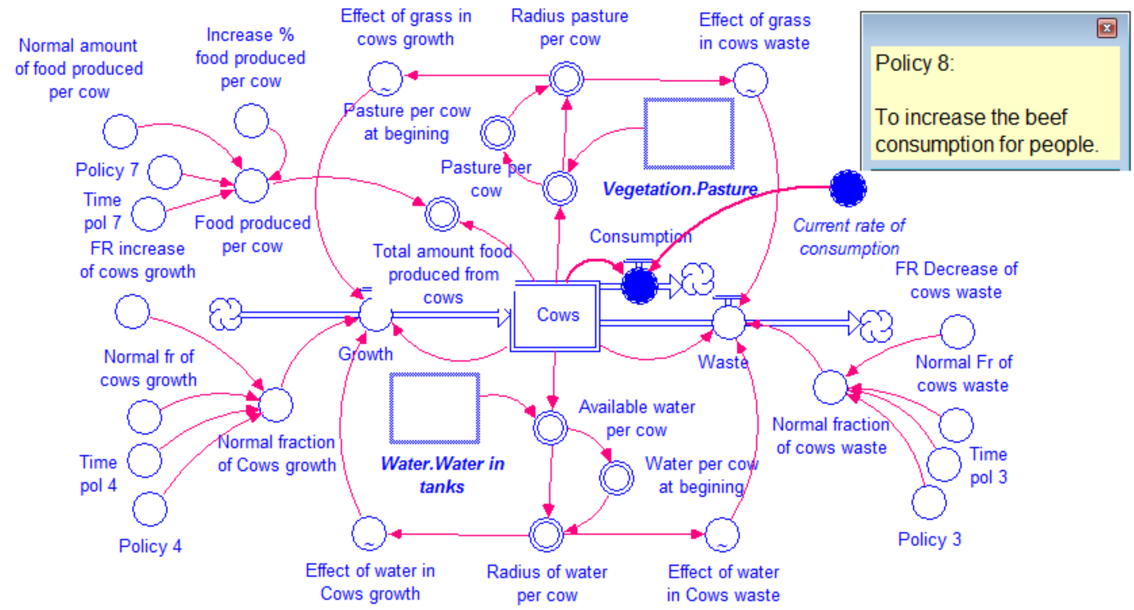
Graph of the vegetation effect in the cows' waste.

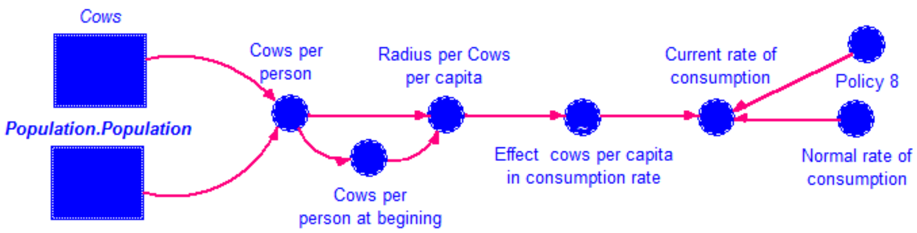


Genetic improvement of animals to increase the milk and meat production.

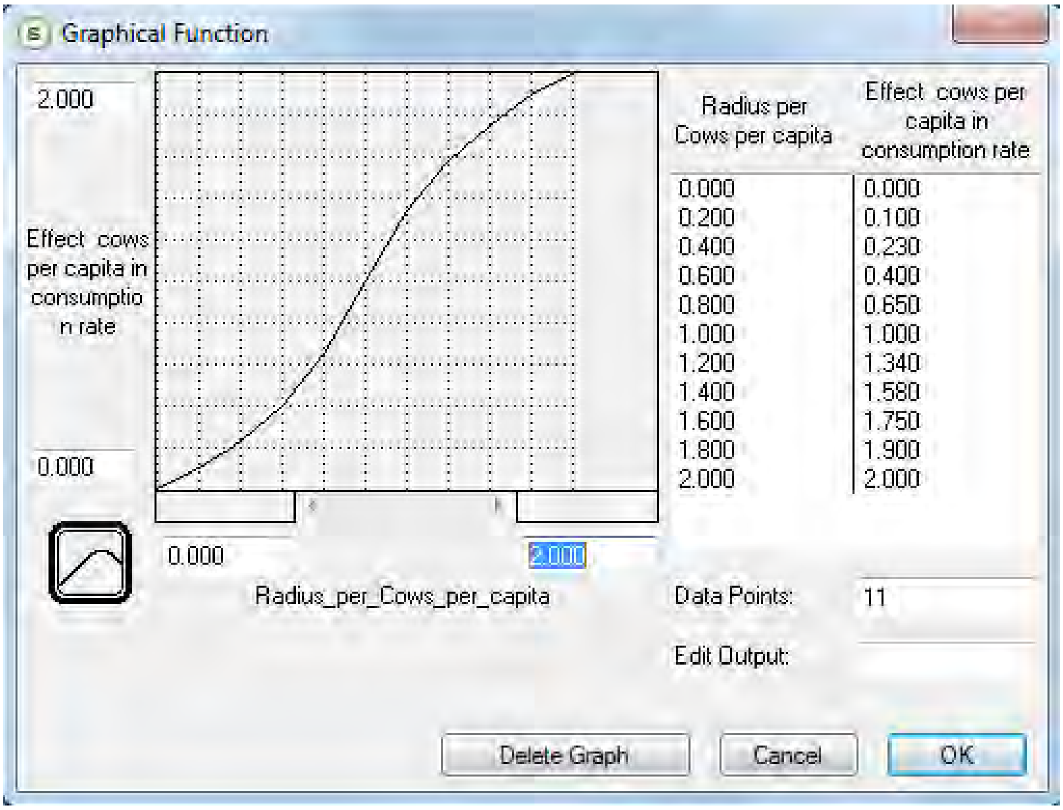


Effect of cows per capita in the consumption rate of meat.





Graph of the effect of the cows per capita in the meat consumption.



Observations

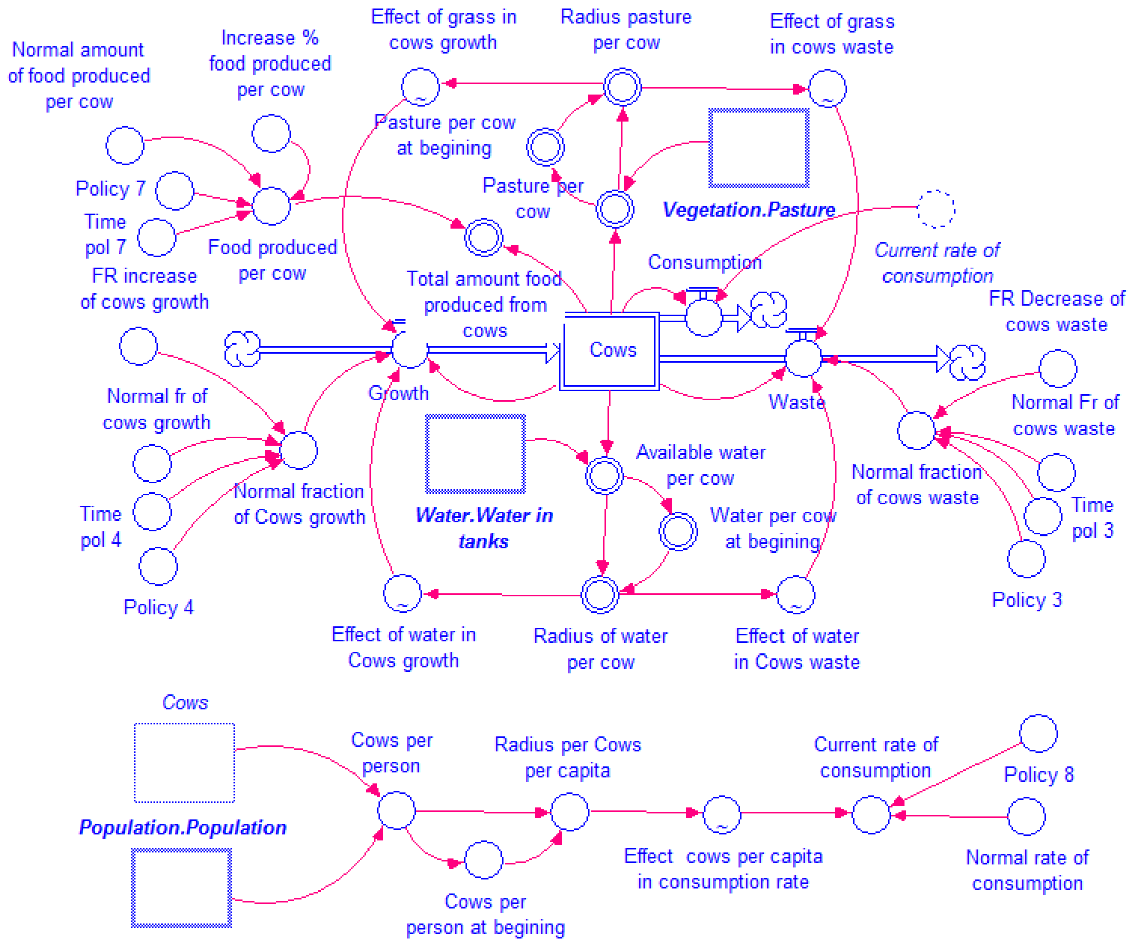
Th rate of normal consumption of meat is affected according to the following assumptions:

1. When the radius of cows per capita is greater than 1, the normal rate of consumption increases by a factor obtained in the graph.
2. Wheh the radius is 1, then the normal rate of consumption stays the same.
3. For radius of cows per capita is less than 1, the normal rate of consumption will be reduced by a factor obtained from the graph.

It's very important to underline that the rate of meat consumption affects only the consumption flow, which means that when the policy to consume more meat than the condemned animal material is accepted, then the slaughter of animals that aren't excusively condemned animal material will be allowed for the animal consumption.

In normal conditions, the slaughter of animals it's only allowed when they have finished their useful life, those animals are called: Condemned animal material, for practical purposes. What means those animals are healthy and their meat can be consumed by humans; if the animal were sick, their consumption would not be allowed (this is the waste flow).

Complete model for the animal dynamics.



Observations:

The complete model to simulate the dynamics for the animal herds includes:

1. The dynamics for the animals growth.
2. The policies for the genetic improvement of reproduction. The productivity of milk and meat products, as the reduction of condemned animal material.
3. The availability effect of water in the dynamics of animal growht.
4. The availability effect of pasture in the animal growht.
5. The effect of the cows per capita in the consumption of beef for humans.
6. The cause effect relationship of the animal herds linked to the vegetation module, the water availability and the dynamics of population.
7. Among the policies implemented to increase the reproductive rate of cows.

Equations of the model for the animal dynamics.

Cows(t) = Cows(t - dt) + (Growth - Waste - Consumption) * dt
INIT Cows = 100
INFLOWS:
Growth =
(Cows*Normal_fraction_of_Cows_growth*Effect_of_grass_in_cows_growth*Effect_of_water_in_Cows_growth)
OUTFLOWS:
Waste =
Cows*Normal_fraction_of_cows_waste*Effect_of_grass_in_cows_waste*Effect_of_water_in_Cows_waste
Consumption = Cows*Current_rate_of_consumption
Available_water_per_cow = Water.Water_in_tanks/Cows
Cows_per_person = Cows/MAX(0.001,Population.Population)
Cows_per_person_at_begining = Init(Cows_per_person)
Current_rate_of_consumption = if (Policy_8=1) then
Normal_rate_of_consumption*Effect__cows_per_capita_in_consumption_rate else 0
Food_produced_per_cow = if (Policy_7=1) then
Normal_amount_of_food_produced_per_cow+STEP((Normal_amount_of_food_produced_per_cow * Increase_%_food_produced_per_cow), Time_pol_7) else Normal_amount_of_food_produced_per_cow
FR_Decrease_of__cows_waste = 0.02
FR_increase_of_cows_growth = 0.02
Increase_%_food_produced_per_cow = 0.25
Normal_amount_of_food_produced_per_cow = 1
Normal_fraction_of_Cows_growth = if (Policy_4=1) then Normal_fr_of_cows_growth+ step(FR_increase_of_cows_growth,Time_pol_4)+ NORMAL(1,.2) else Normal_fr_of_cows_growth
Normal_fraction_of_cows_waste = if (Policy_3=1) then Normal_Fr_of__cows_waste-STEP(FR_Decrease_of__cows_waste,Time_pol_3) else Normal_Fr_of__cows_waste
Normal_fr_of_cows_growth = 0.10
Normal_Fr_of__cows_waste = .1
Normal_rate_of_consumption = 0.01
Pasture_per_cow = Vegetation.Pasture/Cows
Pasture_per_cow_at_begining = Init(Pasture_per_cow)
Policy_3 = 1
Policy_4 = 0
Policy_7 = 0
Policy_8 = 0
Radius_of_water_per_cow = Available_water_per_cow/MAX(0.001,Water_per_cow__at_begining)
Radius_pasture_per_cow = Pasture_per_cow/MAX(0.001,Pasture_per_cow_at_begining)
Radius_per_Cows_per_capita = Cows_per_person/MAX(0.001,Cows_per_person_at_begining)
Time_pol_3 = 2
Time_pol_4 = 2
Time_pol_7 = 2
Total_amount_food_produced_from_cows = Cows*Food_produced_per_cow
Water_per_cow__at_begining = Init(Available_water_per_cow)
Effect_of_grass_in_cows_growth = GRAPH(Radius_pasture_per_cow)
(0.00, 0.00), (0.2, 0.1), (0.4, 0.23), (0.6, 0.4), (0.8, 0.65), (1.00, 1.00), (1.20, 1.34), (1.40, 1.58), (1.60, 1.75), (1.80, 1.90), (2.00, 2.00)
Effect_of_grass_in_cows_waste = GRAPH(Radius_pasture_per_cow)
(0.00, 10.0), (0.2, 6.40), (0.4, 4.05), (0.6, 2.60), (0.8, 1.70), (1.00, 1.00), (1.20, 0.75), (1.40, 0.7), (1.60, 0.7), (1.80, 0.7), (2.00, 0.7)
Effect_of_water_in_Cows_growth = GRAPH(Radius_of_water_per_cow)
(0.00, 0.00), (0.2, 0.62), (0.4, 1.00), (0.6, 1.28), (0.8, 1.48), (1.00, 1.64), (1.20, 1.76), (1.40, 1.86), (1.60, 1.93), (1.80, 1.97), (2.00, 2.00)
Effect_of_water_in_Cows_waste = GRAPH(Radius_of_water_per_cow)
(0.00, 10.0), (0.2, 5.50), (0.4, 3.35), (0.6, 2.15), (0.8, 1.45), (1.00, 1.00), (1.20, 0.8), (1.40, 0.7), (1.60, 0.7), (1.80, 0.7), (2.00, 0.7)
Effect__cows_per_capita_in_consumption_rate = GRAPH(Radius_per_Cows_per_capita)
(0.00, 0.00), (0.2, 0.1), (0.4, 0.23), (0.6, 0.4), (0.8, 0.65), (1.00, 1.00), (1.20, 1.34), (1.40, 1.58), (1.60, 1.75), (1.80, 1.90), (2.00, 2.00)

Other policies and inical data for animals module.

In this module for the animal dynamics, we've created four policies aimed to:

1. Reduce condemned animal material.
2. Improve the animal reproduction.
3. Improve genetics to increase the food production.
4. Increase the human consumption of beef.

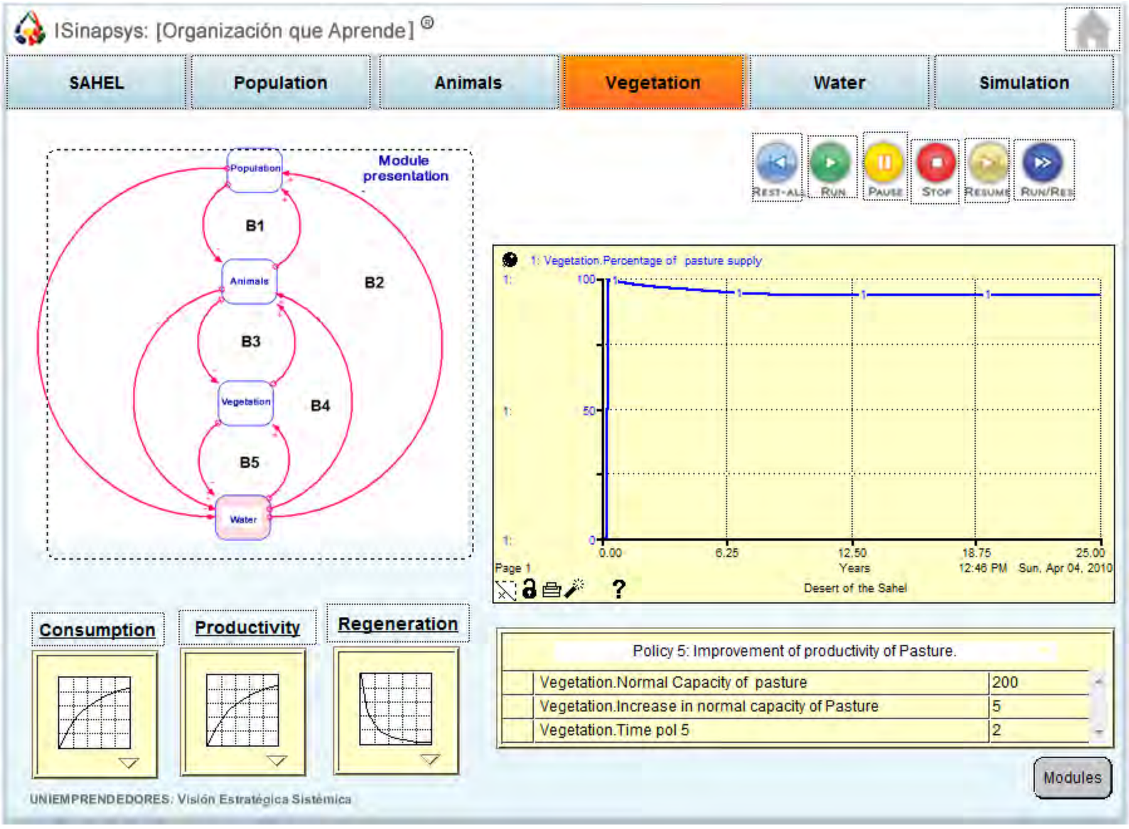
All of them are involved in the genetic improvement of the animals to increase the productivity of their products, improve their reproductive capacity and reduce the natural waste.

The 4th policy applies only when there be enough amount of animals per capita in good conditions, meaning that it's possible to slaughter animals that aren't calsified as condemned animal material.

In addition to pay attention to animal health, other aspects of the ecosystem must be guard, such as:

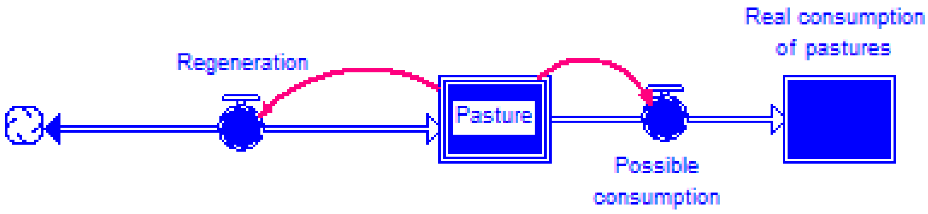
1. The water availability in the surface ponds.
2. The quality of produced grass.

Module for vegetation.



It's included the graph of grass supply for the animal feed.

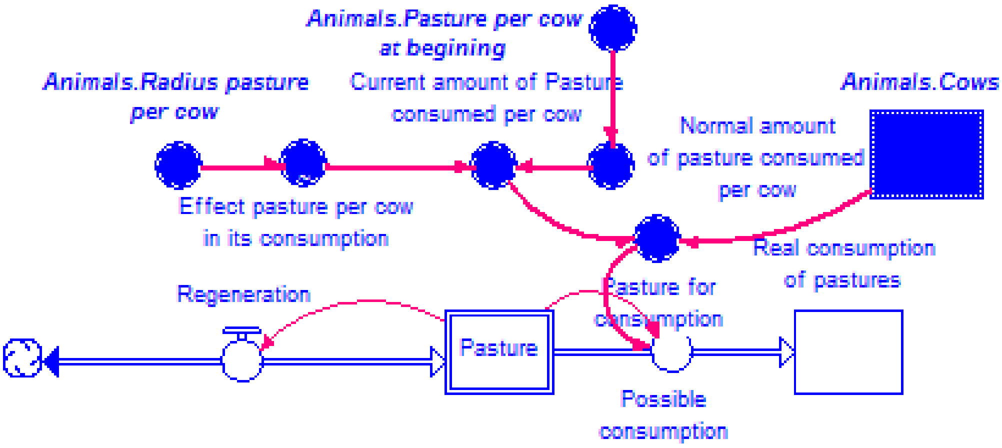
Dynamics for the vegetation management.



Systemic Dynamics for the growth and consumption of pasture.

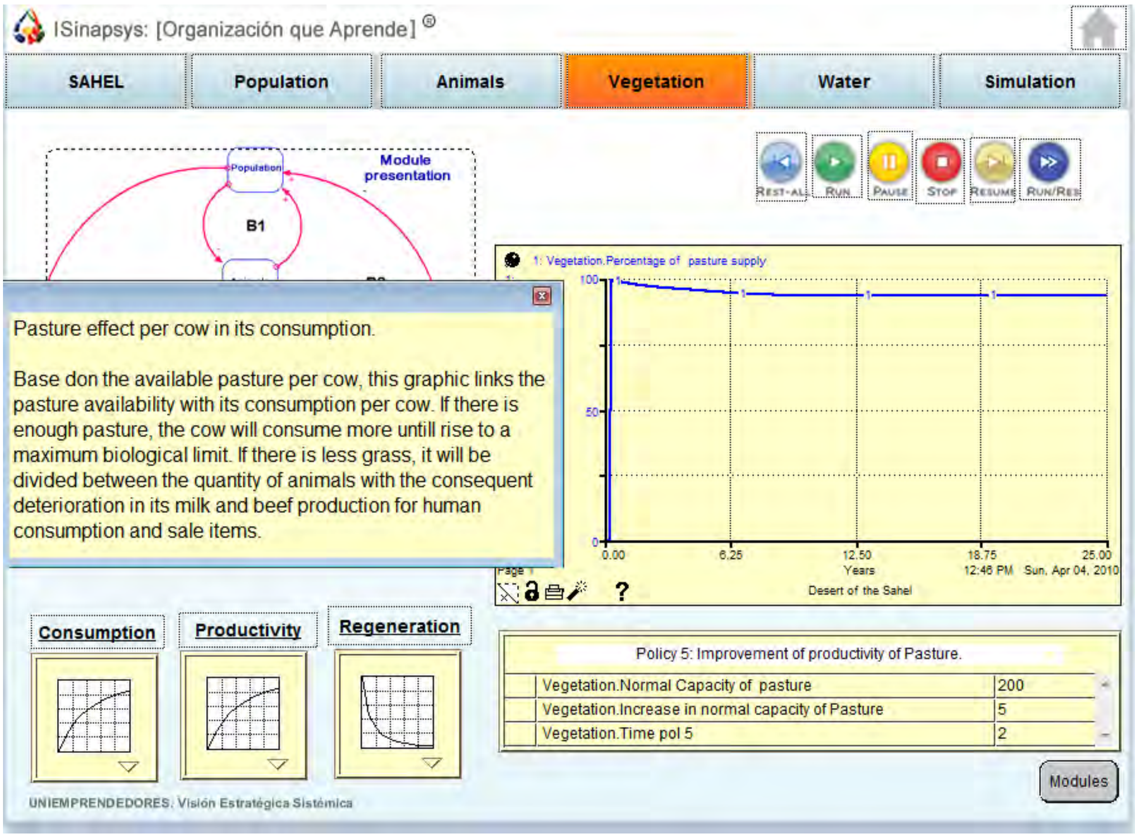
In this module is detailed the logic used to simulate the dynamics for pasture growth, the animal consumption, the increase of productivity given by the availability of water and the improvement of the seeding techniques, the impact of productivity in the natural time of pasture regeneration.

Effect of the pasture availability in the animal consumption.

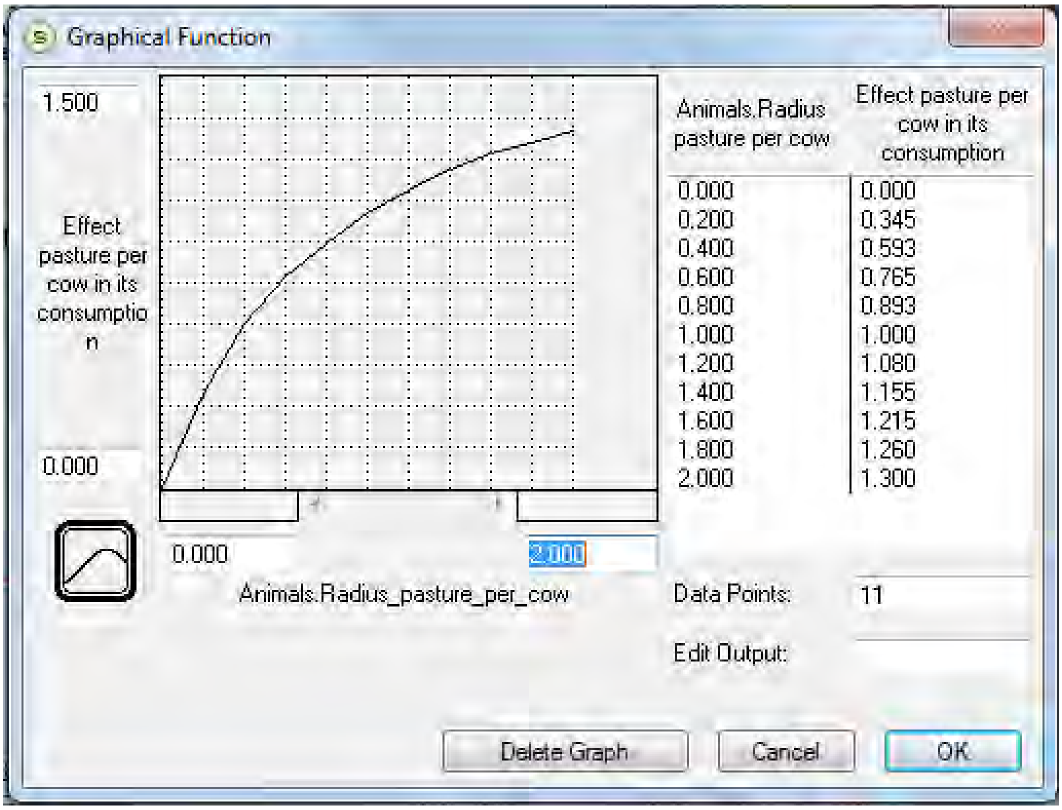


Here is shown the effect that the availability of pasture has in the animal consumption, the high the availability, the high the consumption untill rise to a maximum biological limit consumption per animal.

Description of the effect of the pasture availability in the consumption.

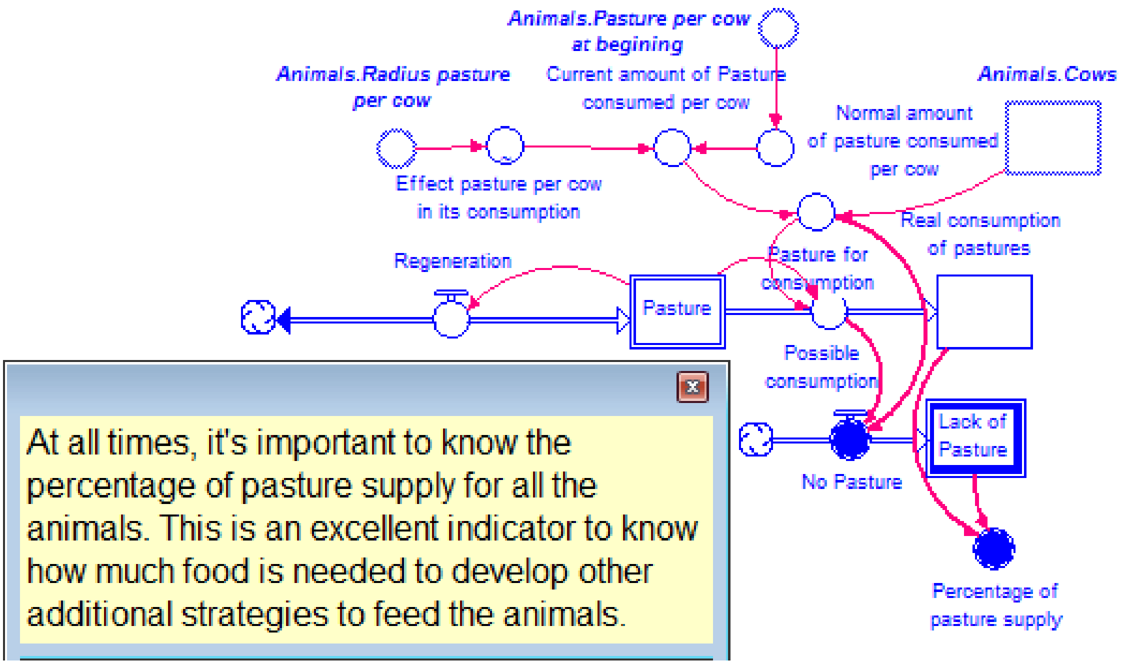


Graph of the effect of pasture availability in the animal consumption.

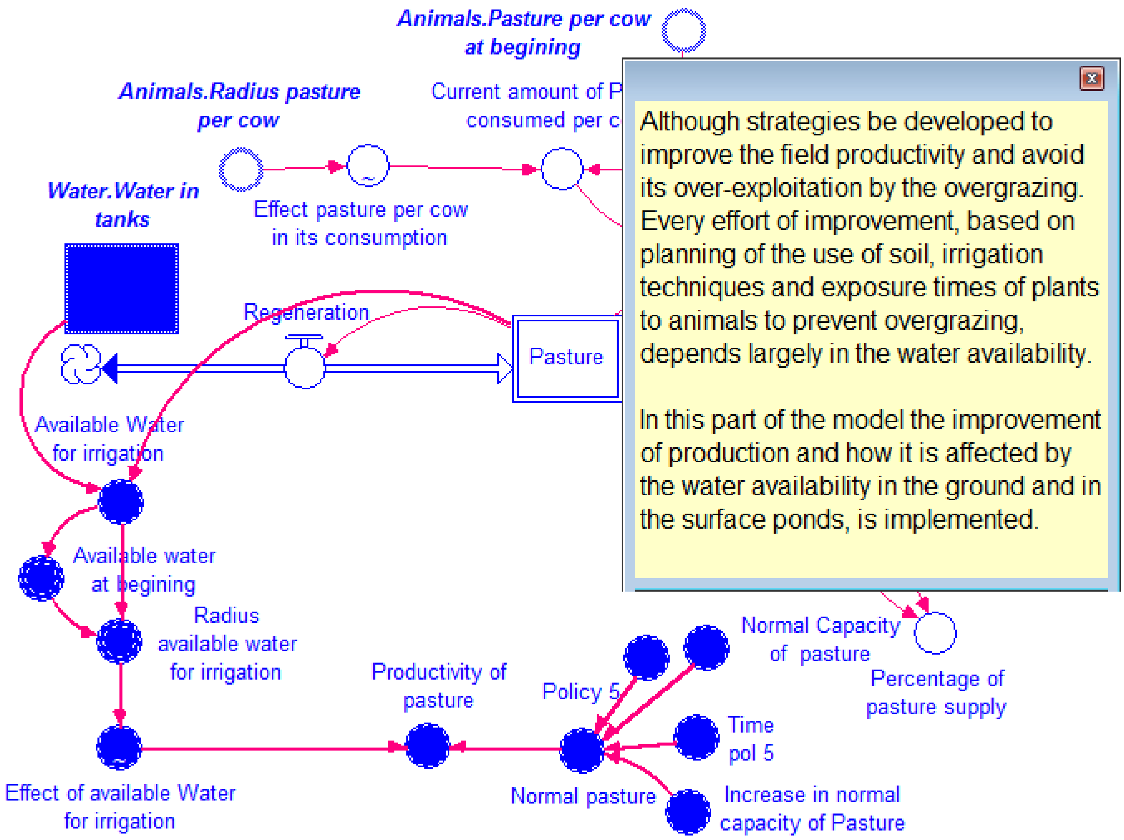


Animals.Radius pasture per cow	Effect pasture per cow in its consumption
0.000	0.000
0.200	0.345
0.400	0.593
0.600	0.765
0.800	0.893
1.000	1.000
1.200	1.080
1.400	1.155
1.600	1.215
1.800	1.260
2.000	1.300

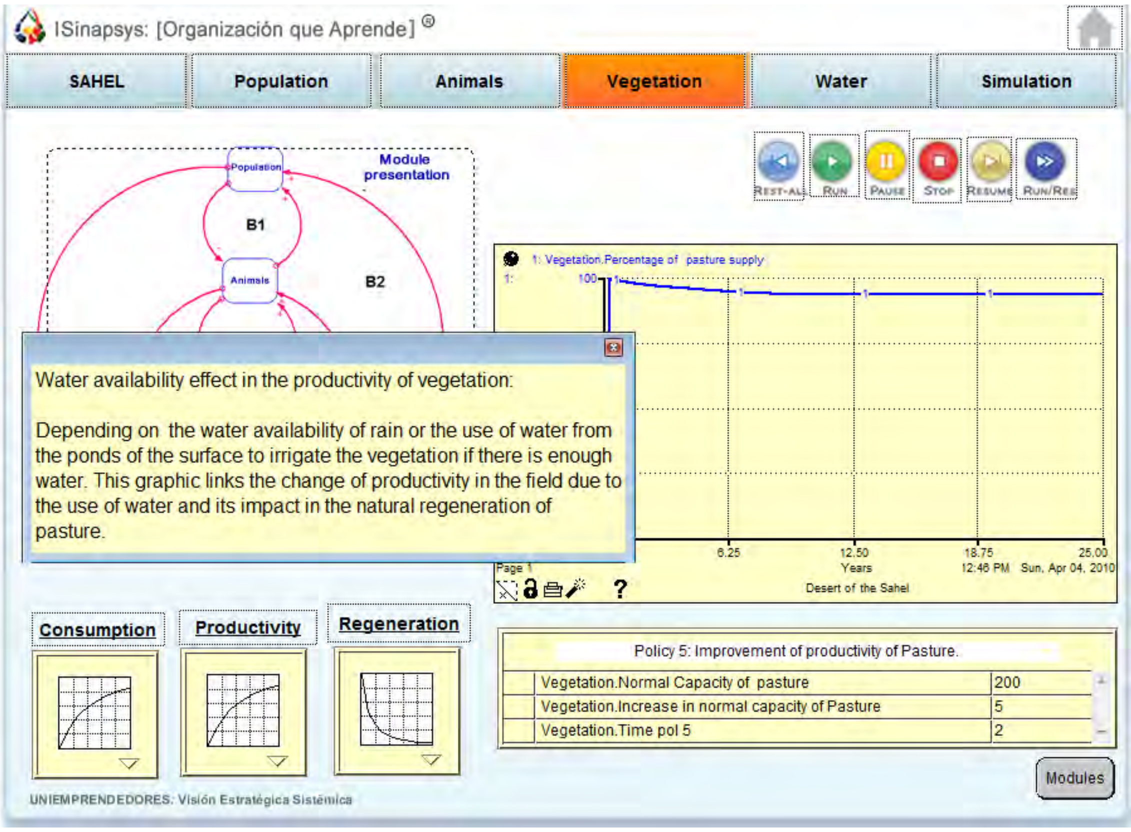
Percentage indicator for the pasture supply.



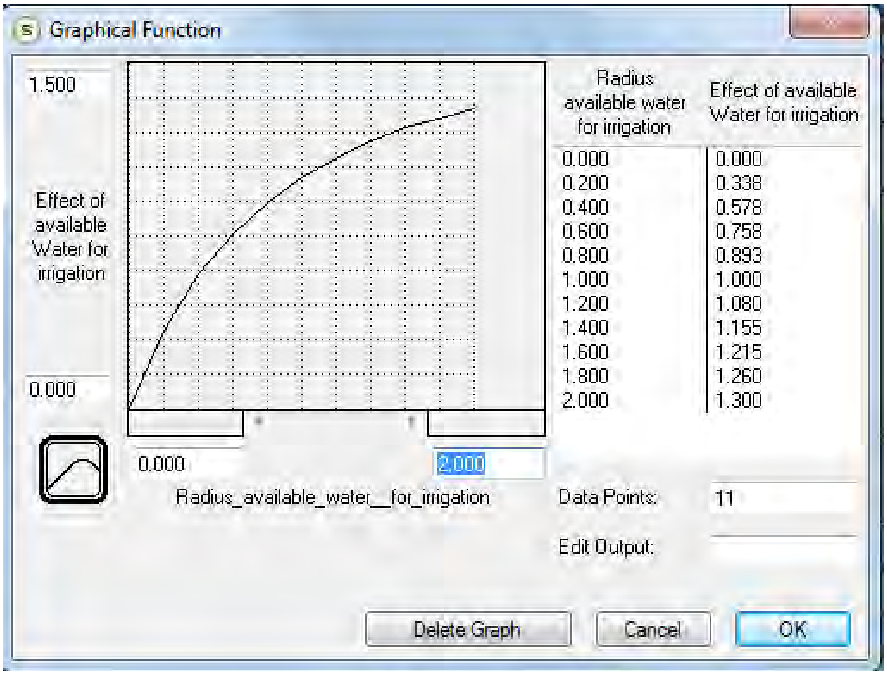
Effect of the water availability in the field productivity.



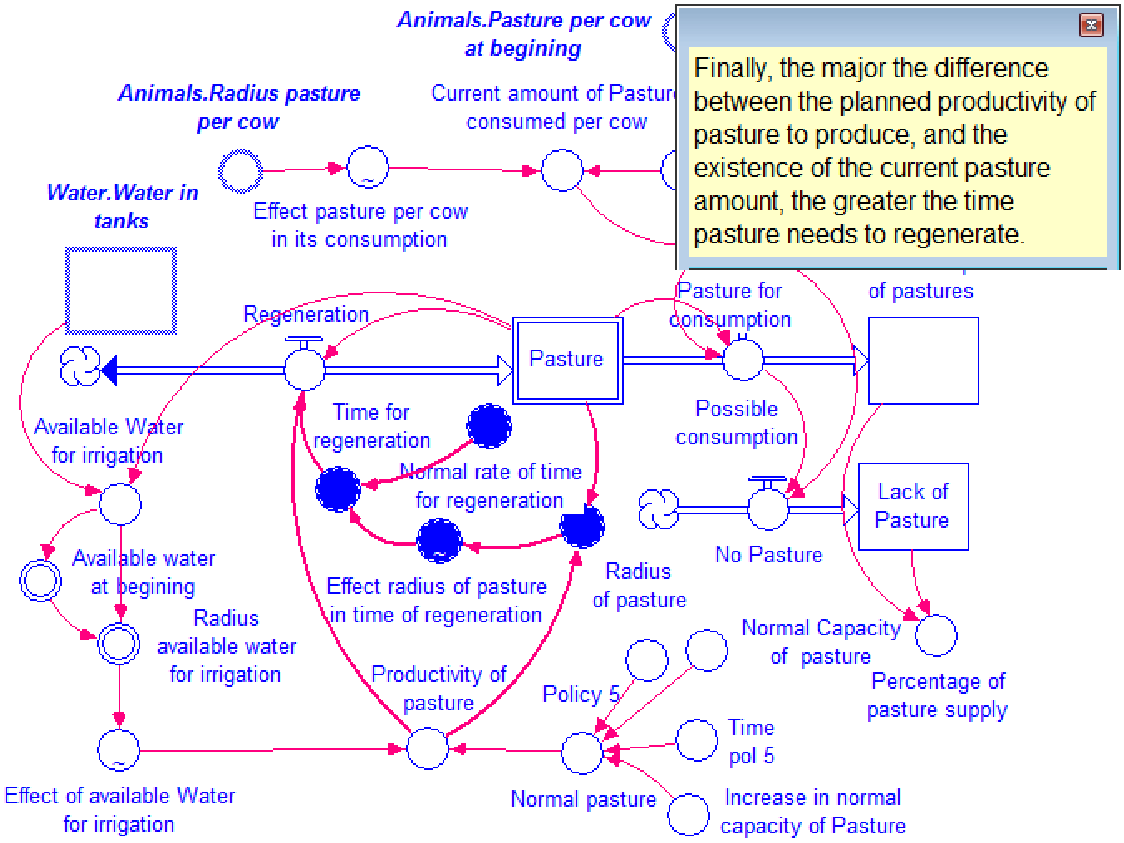
Description of the water effect in the productivity of pasture.



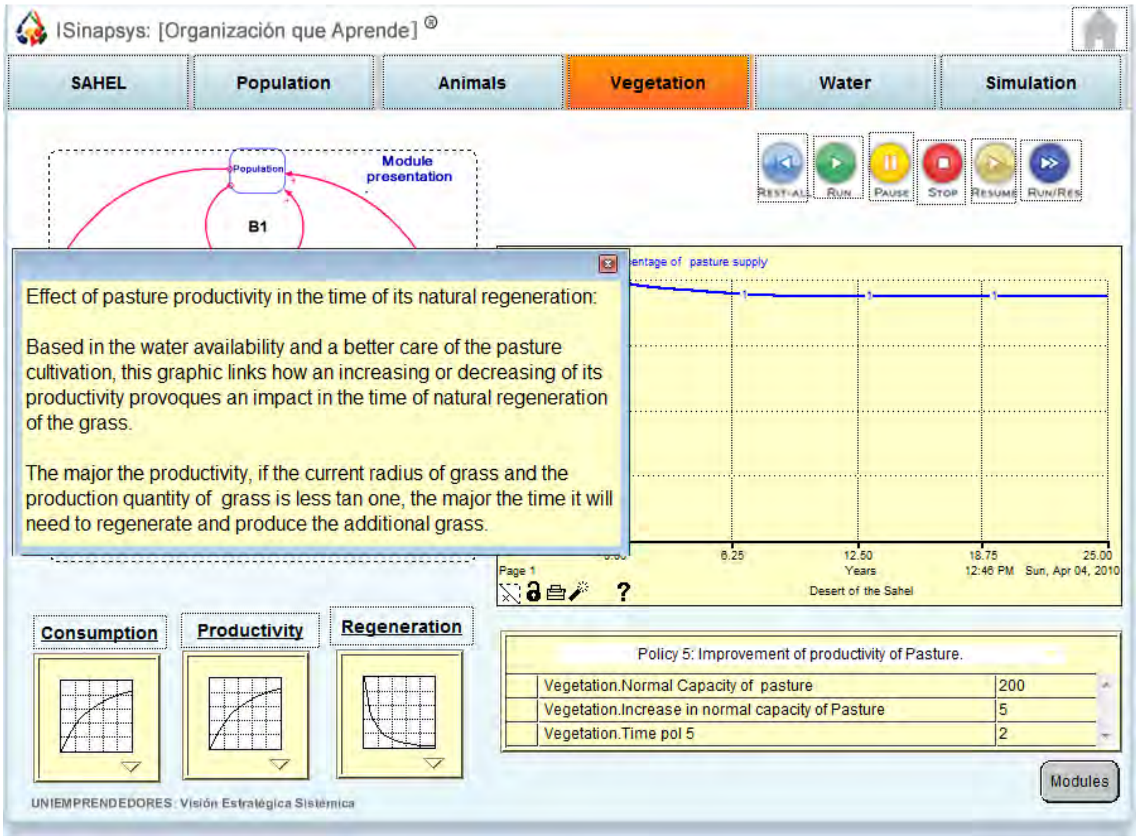
Graph of the effect in the availability of water for the pasture productivity.



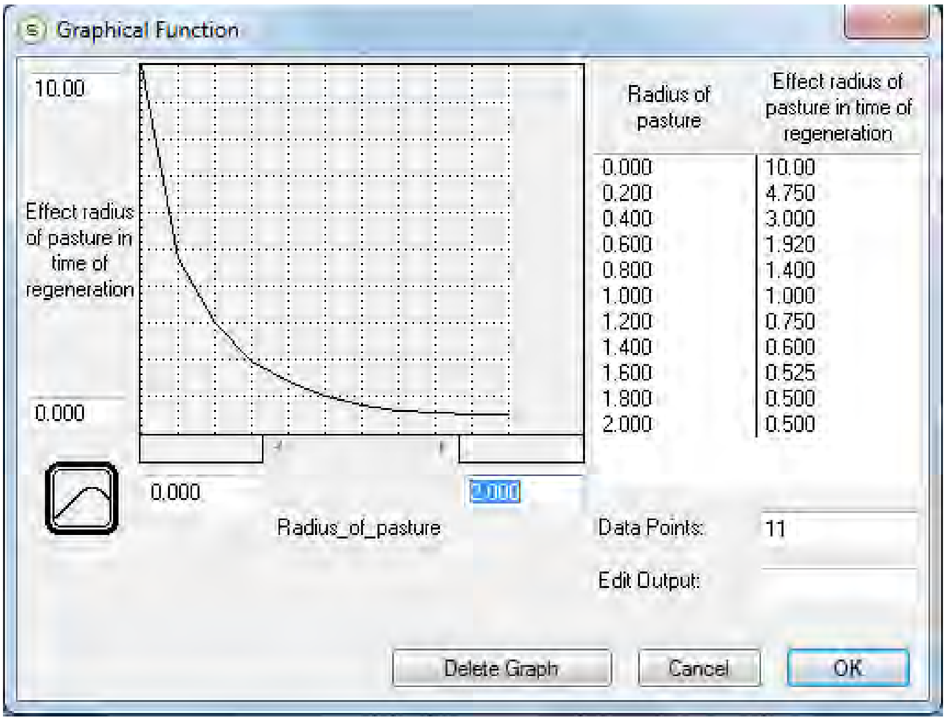
Effect of the pasture productivity on its regenerative time.



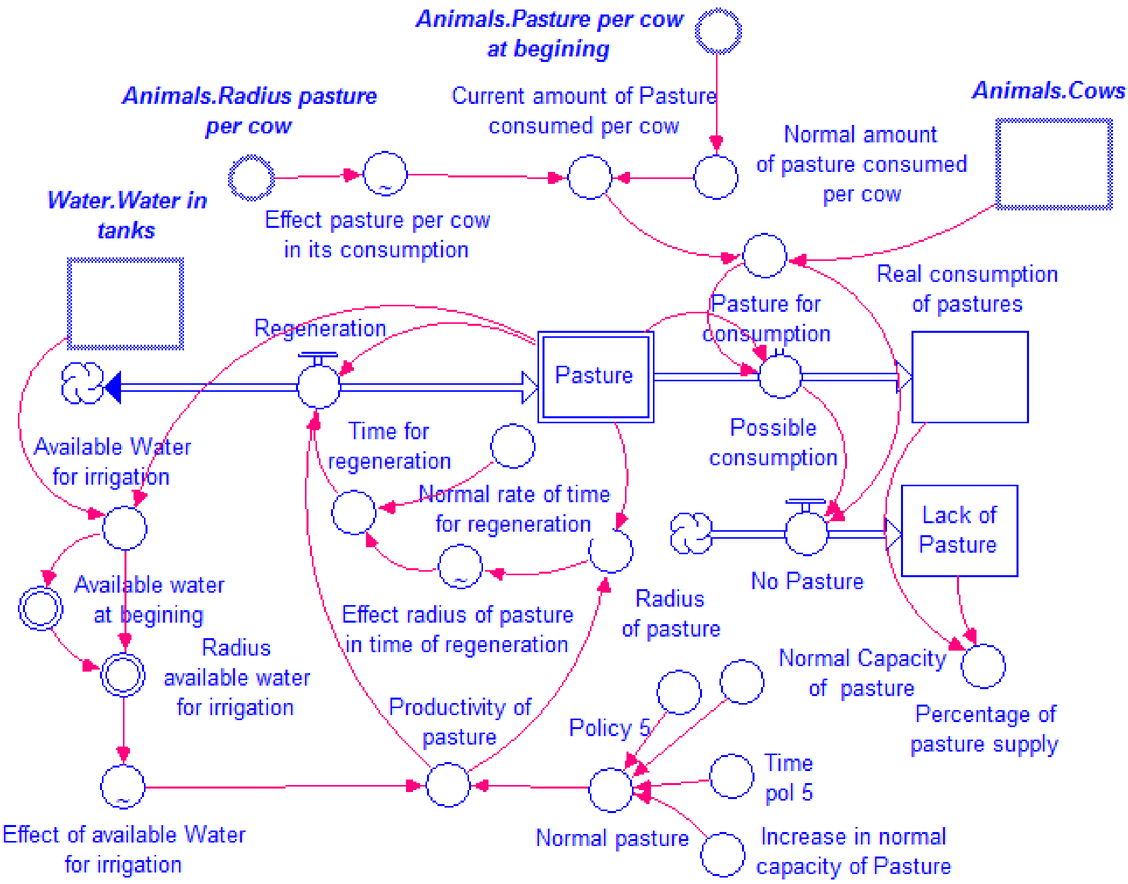
Description of the effect in the pasture productivity on its regenerative time.



Graph of the effect in the pasture productivity on its regenerative time.



Complete model for the pasture Dynamics.



Observations:

The complete model to simulate the animal herds dynamics, includes:

1. The pasture's growth dynamics.
2. The policy to improve the pasture productivity.
3. The effect of the pasture availability in the animal consumption.
4. The effect of the water availability in the pasture production.
5. The effect of the pasture's radius (Productivity) in the recovery time that vegetation needs.
6. The logic of calculation to determine the supply percentage of pasture (Animal feed) at all times.
7. The cause-effect relationship between vegetation and the animal modules with water consumption in the irrigation of pastures.
8. Among the implemented policy to increase the productivity of pastures production, the data about the increase of production capacity of the normal pasture and the time it takes to occur, is recorded.

Equations for the pastures model.

Lack_of__Pasture(t) = Lack_of__Pasture(t - dt) + (No_Pasture) * dt

INIT Lack_of__Pasture = 0

INFLOWS:

No_Pasture = if Pasture_for__consumption>Possible_consumption then Pasture_for__consumption-Possible_consumption else 0

Pasture(t) = Pasture(t - dt) + (Regeneration - Possible_consumption) * dt

INIT Pasture = 100

INFLOWS:

Regeneration = (Productivity_of_pasture-Pasture)/Time_for_regeneration

OUTFLOWS:

Possible_consumption = if (Pasture>Pasture_for__consumption) then Pasture_for__consumption else Pasture

Real_consumption_of_pastures(t) = Real_consumption_of_pastures(t - dt) + (Possible_consumption) * dt

INIT Real_consumption_of_pastures = 0

INFLOWS:

Possible_consumption = if (Pasture>Pasture_for__consumption) then Pasture_for__consumption else Pasture

Available_water_at_begining = Init(Available_Water_for_irrigation)

Available_Water_for_irrigation = Water.Water_in_tanks/MAX(0.001,Pasture)

Current_amount_of_Pasture_consumed_per_cow = Normal_amount__of_pasture_consumed__per_cow*Effect_pasture_per_cow_in_its_consumption

Increase_in_normal_capacity_of_Pasture = 5

Normal_amount__of_pasture_consumed__per_cow = Animals.Pasture_per_cow_at_begining

Normal_Capacity_of__pasture = 200

Normal_pasture = if (Policy_5=1) then Normal_Capacity_of__pasture+NORMAL(1,.1)+STEP(Increase_in_normal_capacity_of_Pasture,Time_pol_5) else Normal_Capacity_of__pasture

Normal_rate_of_time_for_regeneration = 1

Pasture_for__consumption = Animals.Cows*Current_amount_of_Pasture_consumed_per_cow

Percentage_of__pasture_supply = if (Real_consumption_of_pastures+Lack_of__Pasture)=0 then 0 else Real_consumption_of_pastures/(Real_consumption_of_pastures+Lack_of__Pasture)*100

Policy_5 = 0

Productivity_of_pasture = Normal_pasture*Effect_of_available_Water_for_irrigation

Radius_available_water__for_irrigation = Available_Water_for_irrigation/MAX(0.001,Available_water_at_begining)

Radius_of_pasture = (Pasture/Productivity_of_pasture)*2

Time_for_regeneration = Normal_rate_of_time_for_regeneration*Effect_radius_of_pasture_in_time_of_regeneration

Time_pol_5 = 2

Effect_of_available_Water_for_irrigation = GRAPH(Radius_available_water__for_irrigation)

(0.00, 0.00), (0.2, 0.338), (0.4, 0.578), (0.6, 0.757), (0.8, 0.892), (1.00, 1.00), (1.20, 1.08), (1.40, 1.16), (1.60, 1.22), (1.80, 1.26), (2.00, 1.30)

Effect_pasture_per_cow_in_its_consumption = GRAPH(Animals.Radius_pasture_per_cow)

(0.00, 0.00), (0.2, 0.345), (0.4, 0.593), (0.6, 0.765), (0.8, 0.892), (1.00, 1.00), (1.20, 1.08), (1.40, 1.16), (1.60, 1.22), (1.80, 1.26), (2.00, 1.30)

Effect_radius_of_pasture_in_time_of_regeneration = GRAPH(Radius_of_pasture)

(0.00, 10.0), (0.2, 4.75), (0.4, 3.00), (0.6, 1.92), (0.8, 1.40), (1.00, 1.00), (1.20, 0.75), (1.40, 0.6), (1.60, 0.525), (1.80, 0.5), (2.00, 0.5)

Policies and initial data for the vegetation module.

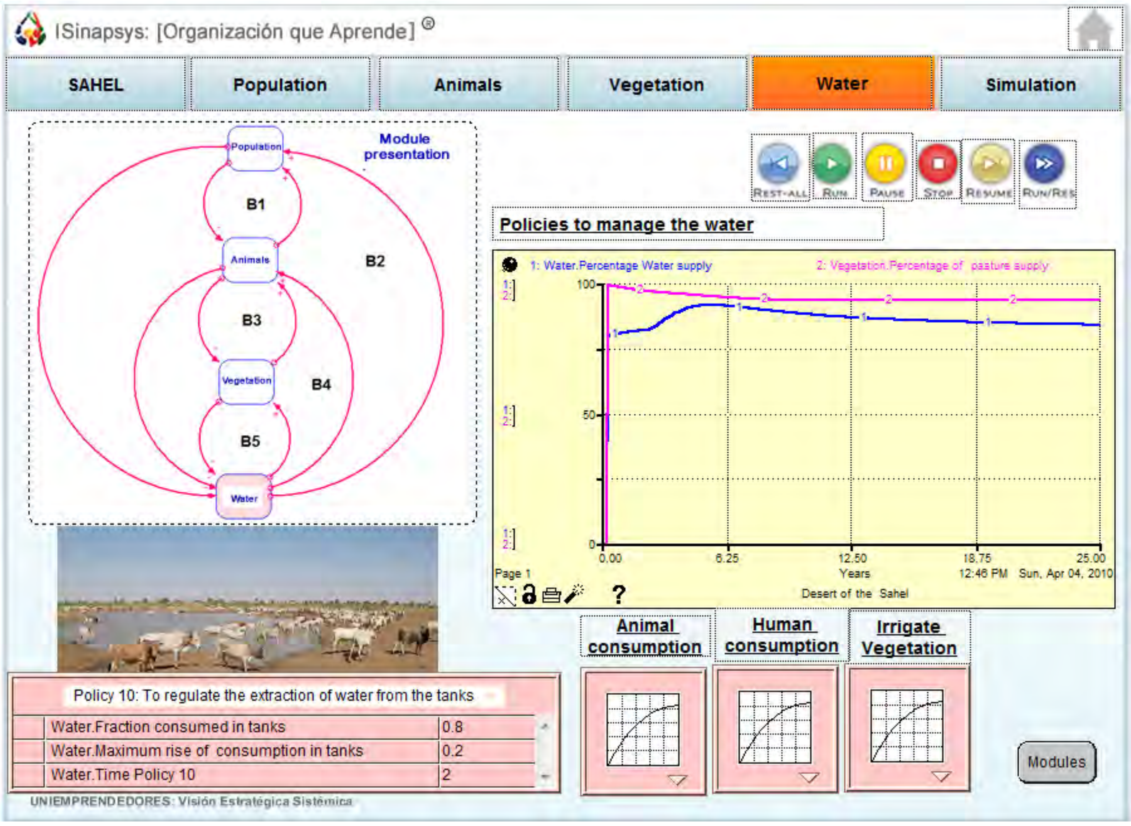
In this module for the vegetation dynamics, we've created a policy aimed at:

1. The improvement of pasture productivity.

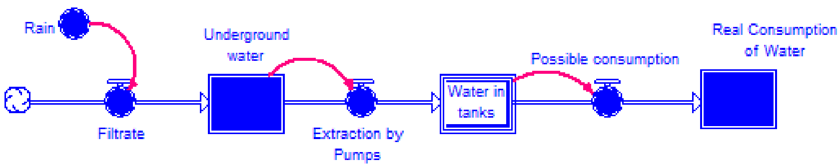
This is closely related to the water availability, any strategy to improve the plantation of grasses, including take a great care of overgrazing, can be implemented, but anyone will work without water.

Although generally the vegetation is only watered with rainwater, a policy in the water module has been implemented. This policy establishes that if there is enough water, it can be used directly from the ponds of the surface to water in times when it doesn't rain. The result of the simulation shows us this isn't a good policy, and this conclusion agrees with the knowledge we have about the Sael, since 1960 to date, there is a chronic shortage of rainfall. See the chart below:

Module for the water.



System dynamics to simulate the behavior of the water flow. (Since it rains up until its consumption).



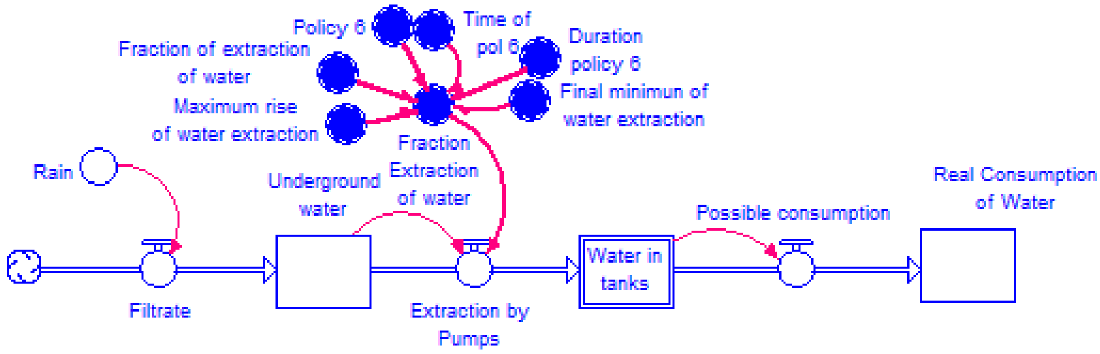
System dynamics to simulate the behavior of the water flow that follows the following steps:

1. Everything starts with rain.
2. The rainfall is filtered and stored in the underground.
3. Policies are defined to manage the use of water pumped from underground to the ponds.
4. A policy to control the water consumption from ponds is implemented.
5. Supply statistics are created.

Note: An important amoun of rainfall evaporates, the evaporation logic is omited to simplify the model.

Fort he case of rain, there exist complex mathematical models to forecast rains. In this case a simplification based on the normal statistics in implemented.

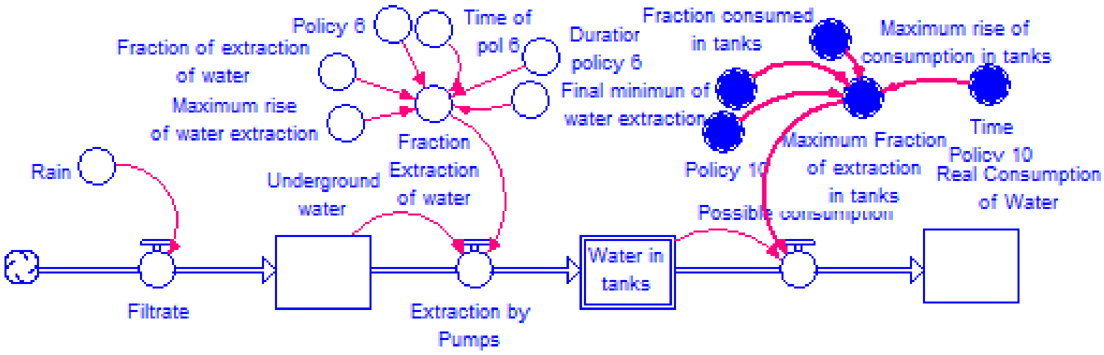
Pumping water from deep wells to surface ponds.



Policy 6: To manage the pumping of water from the deep wells to the ponds:

In this section de data needed to control the flow of water pumped from the wells to the storage ponds is described.

Policy to increase the consumption of water from the pond.

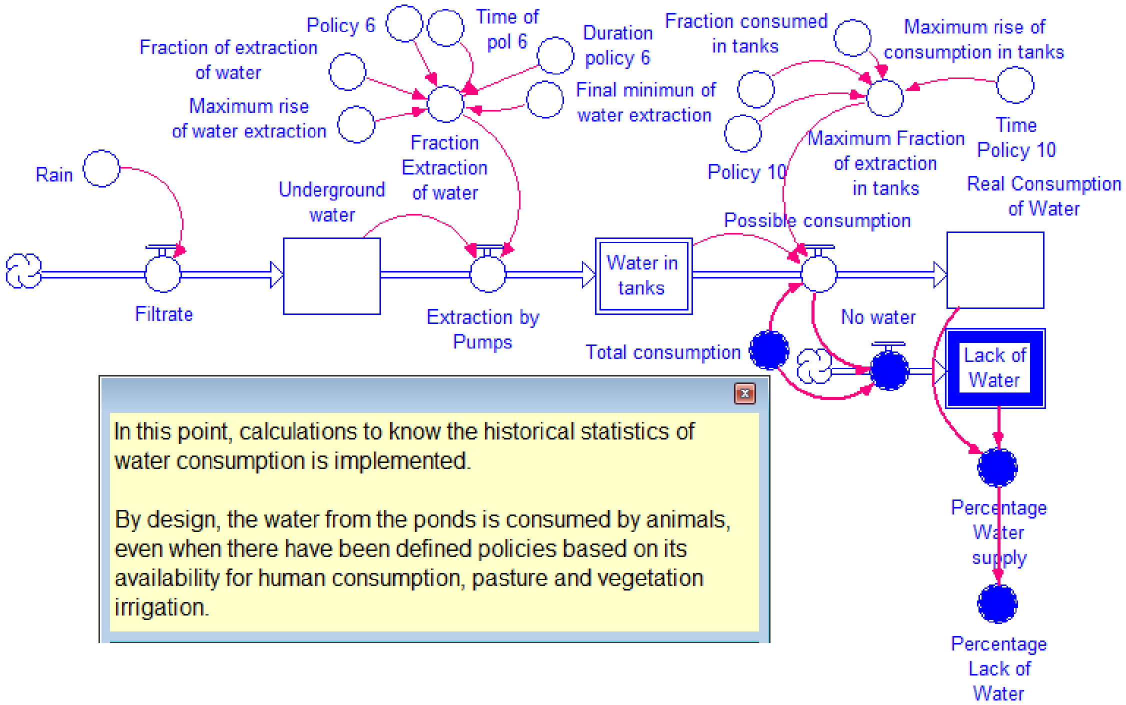


Policy 10: To manage the use of water consumed in the ponds:

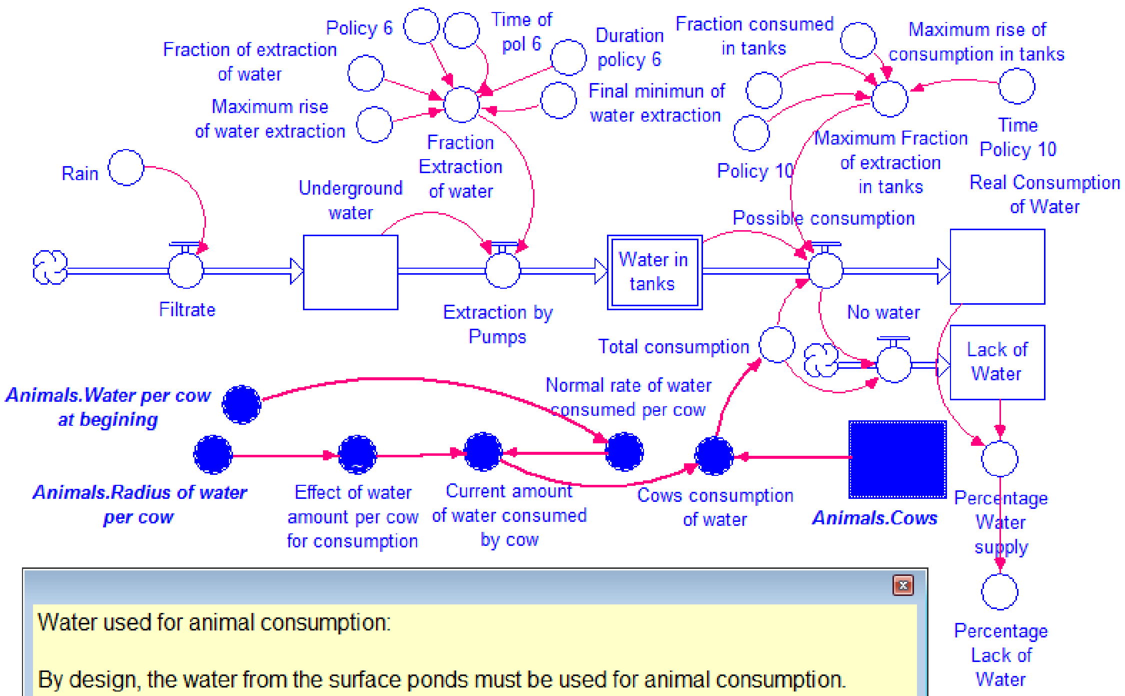
In this case, the rules to follow with the consumption of stored water in the ponds of the surface is clarified.

The water from ponds of the surface is commonly used for animal consumption. Two additional policies have been developed, based on the vital liquid availability, through those policies it's possible to use the water for human consumption and also to water the pastures as a complement to the rainwater (this is documented below). Although the water flow from the ponds increases, this is not much help, in the Sael, the water is in crisis, drought is chronic since decades ago and the simulation will show us that strategies of mayor water use, aren't good. It's necessary to bent on a responsible use and care of this resource.

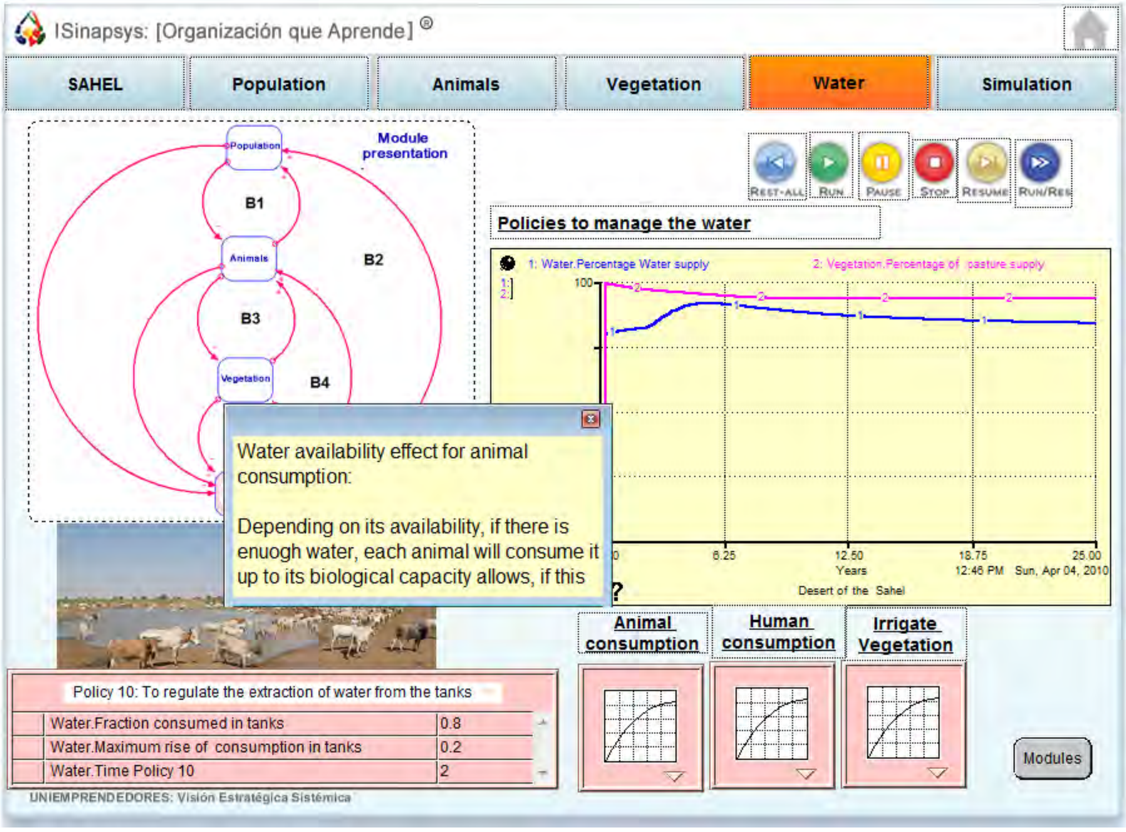
Statistical history of water consumption.



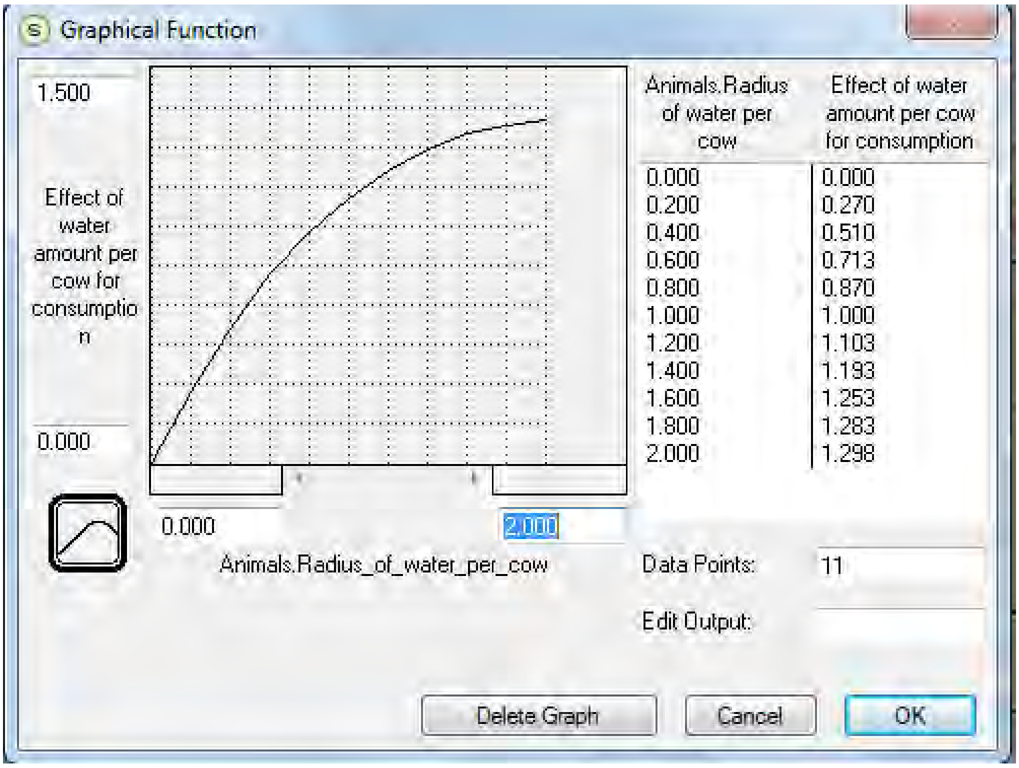
Water used for animal consumption.



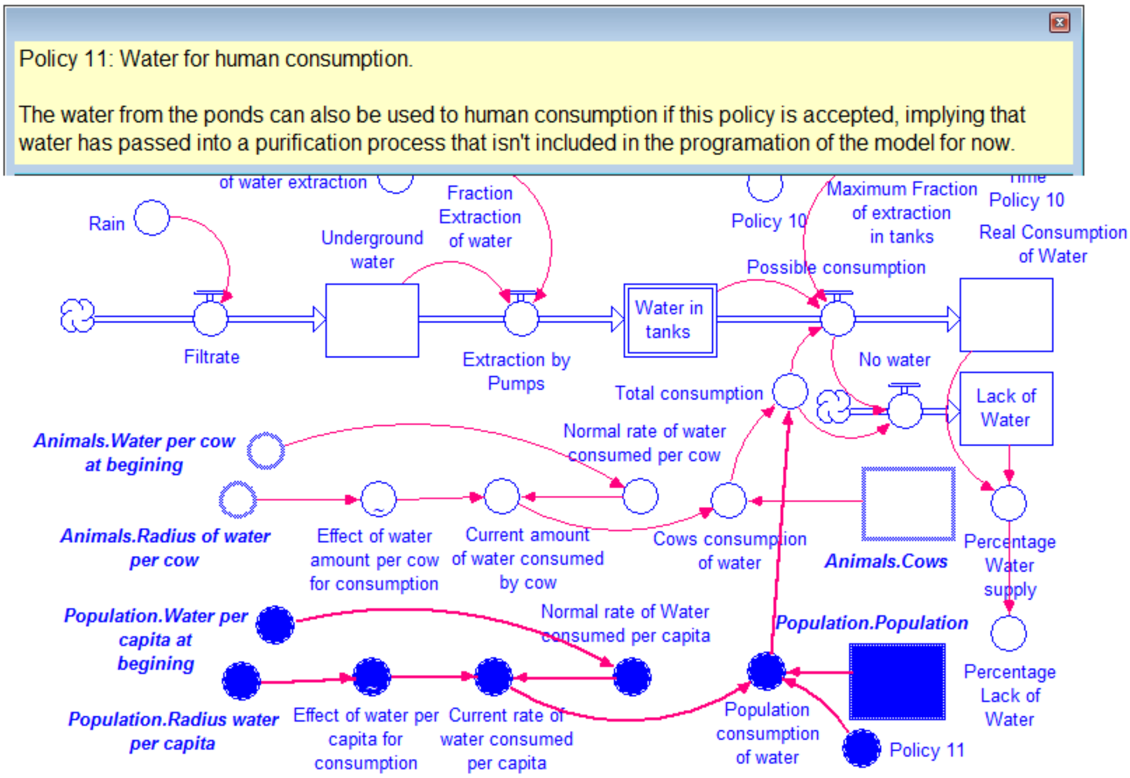
Description of the effect in the water availability for the animal consumption.



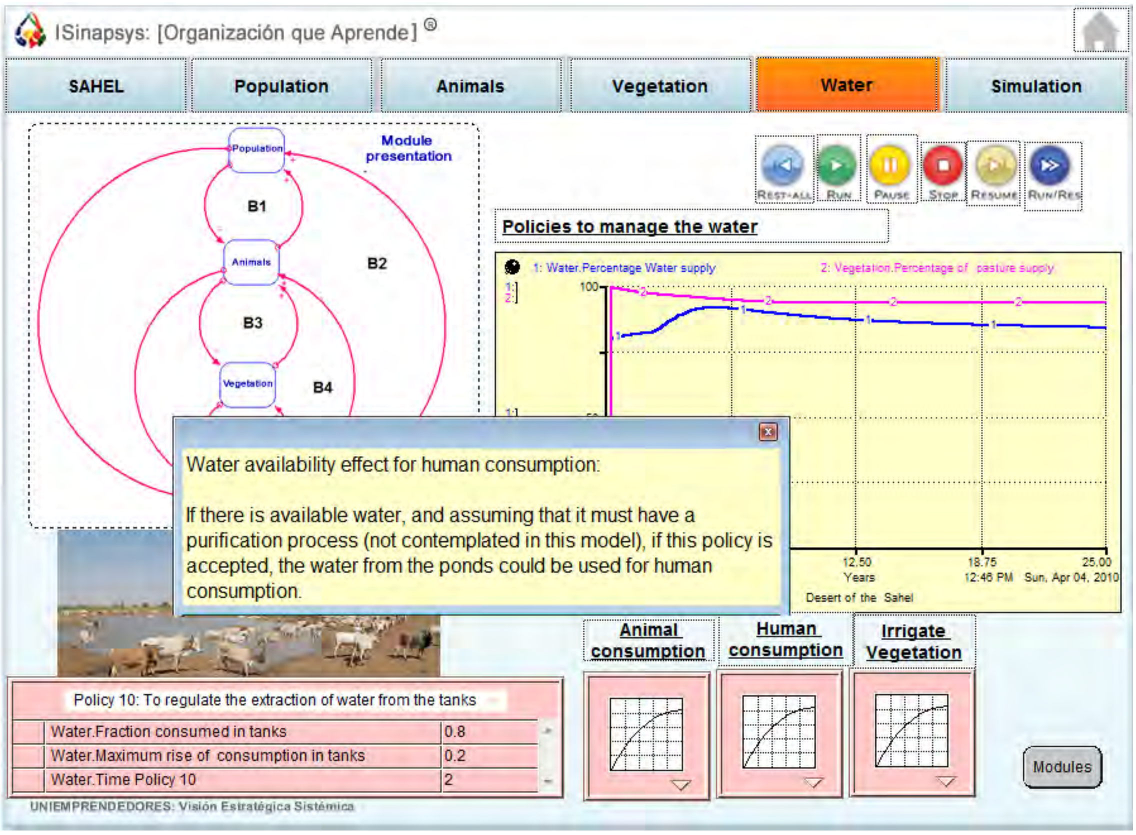
Graph of the water effect per cow by the animal consumption.



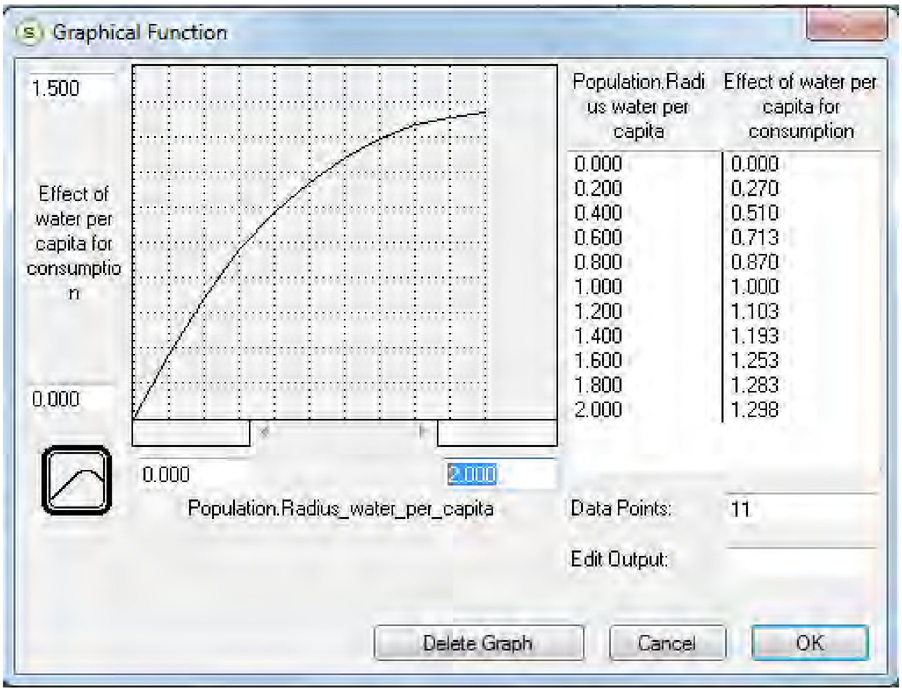
Water policy for human consumption.



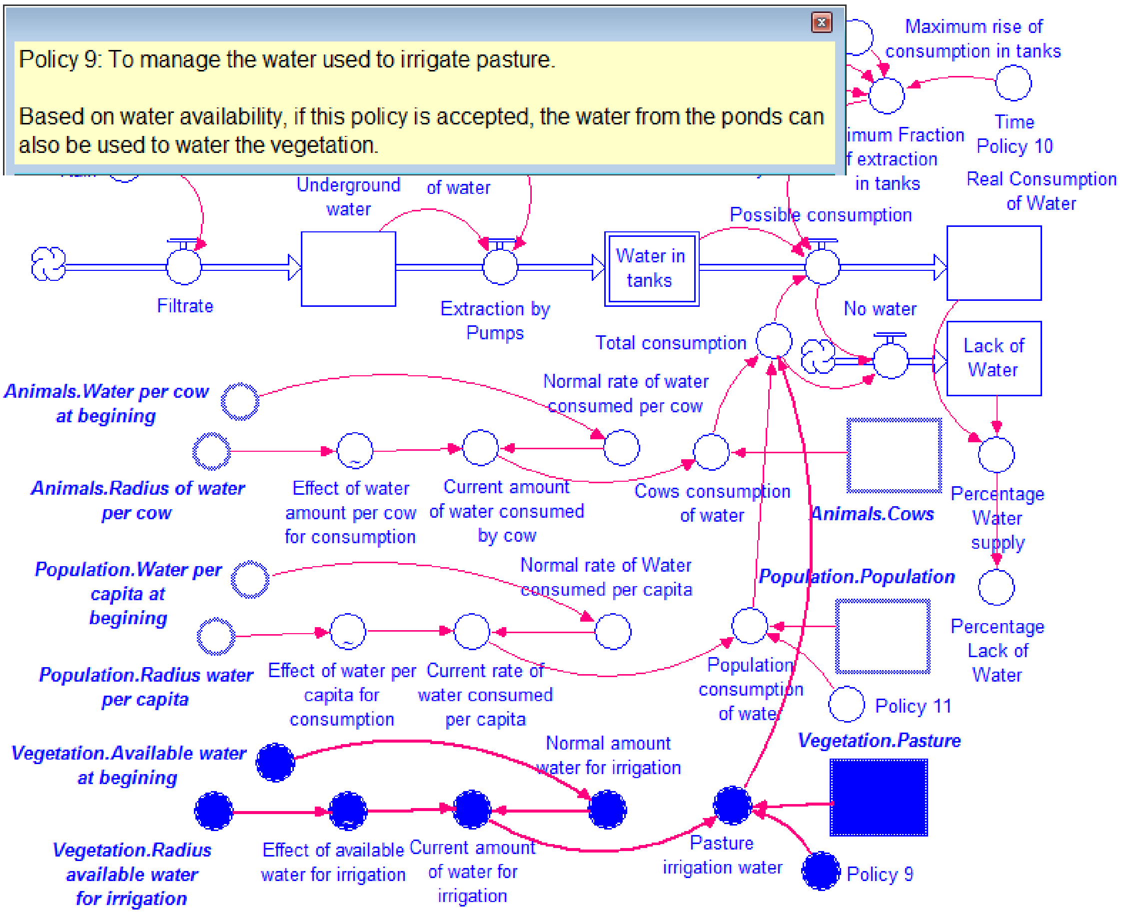
Policy description for water use for human conumption.



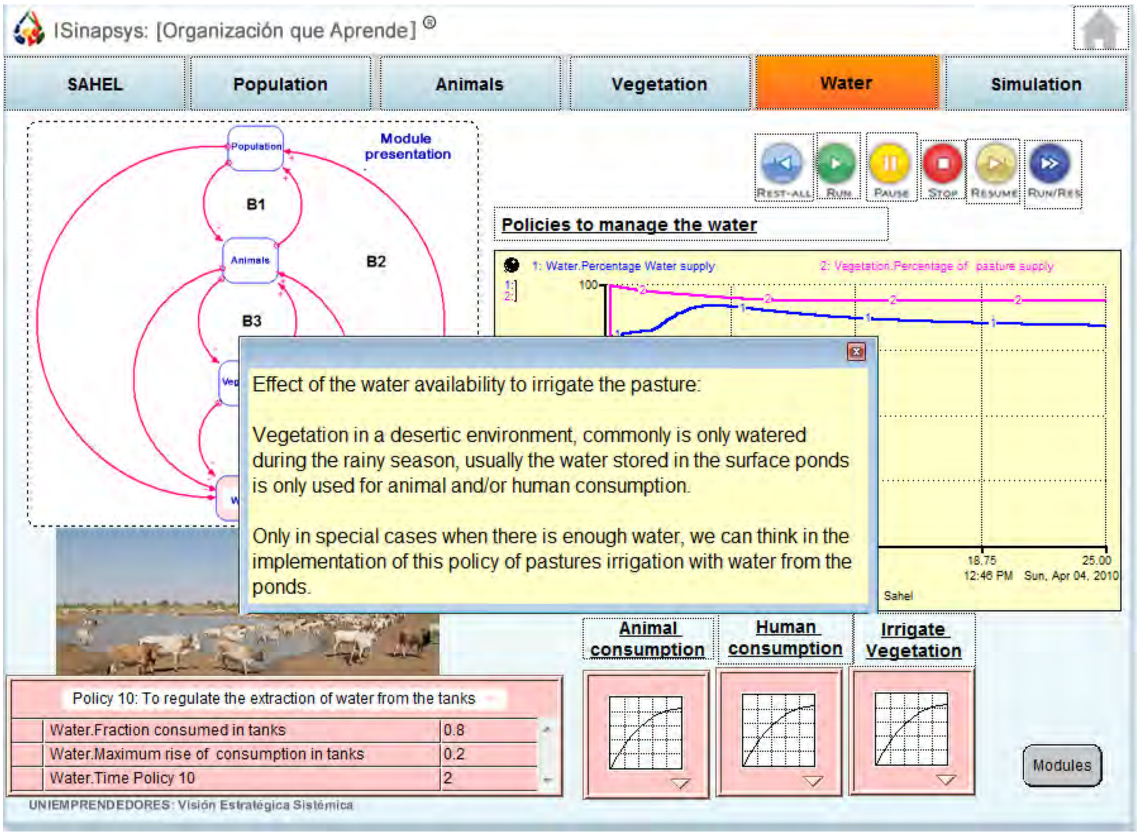
Graph of the water effect per capita for human consumption.



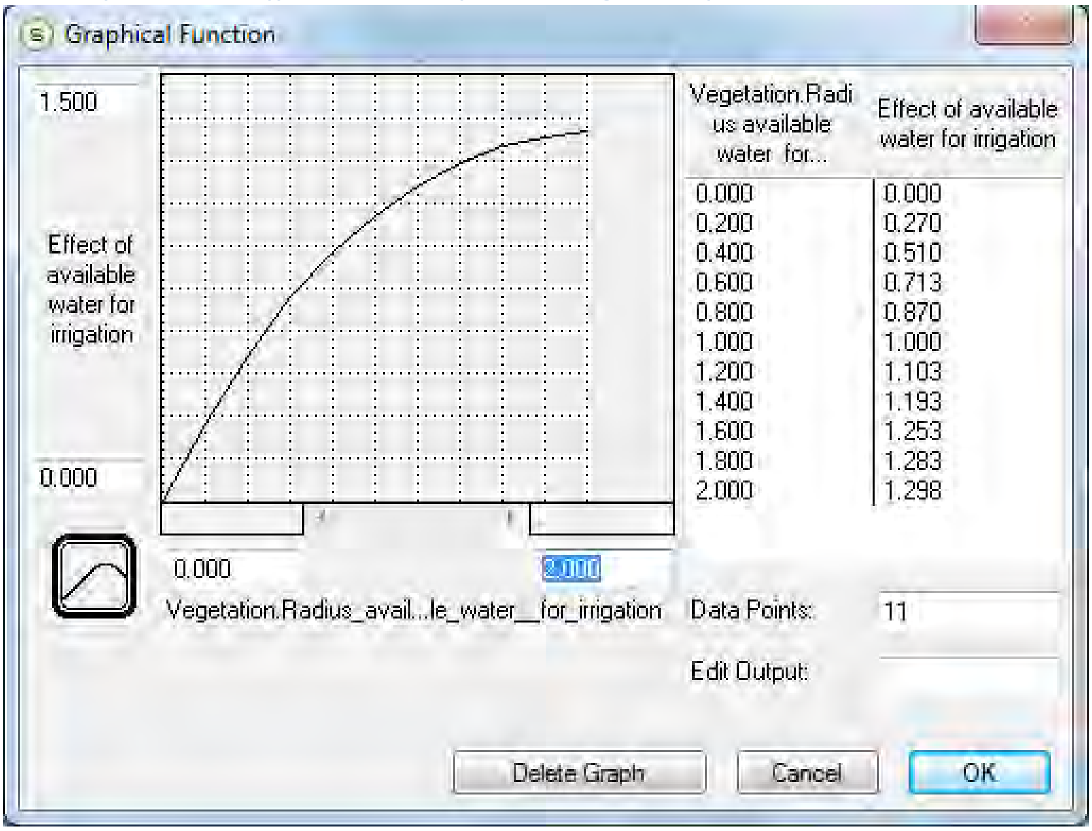
Policy for water use for irrigation of vegetation.



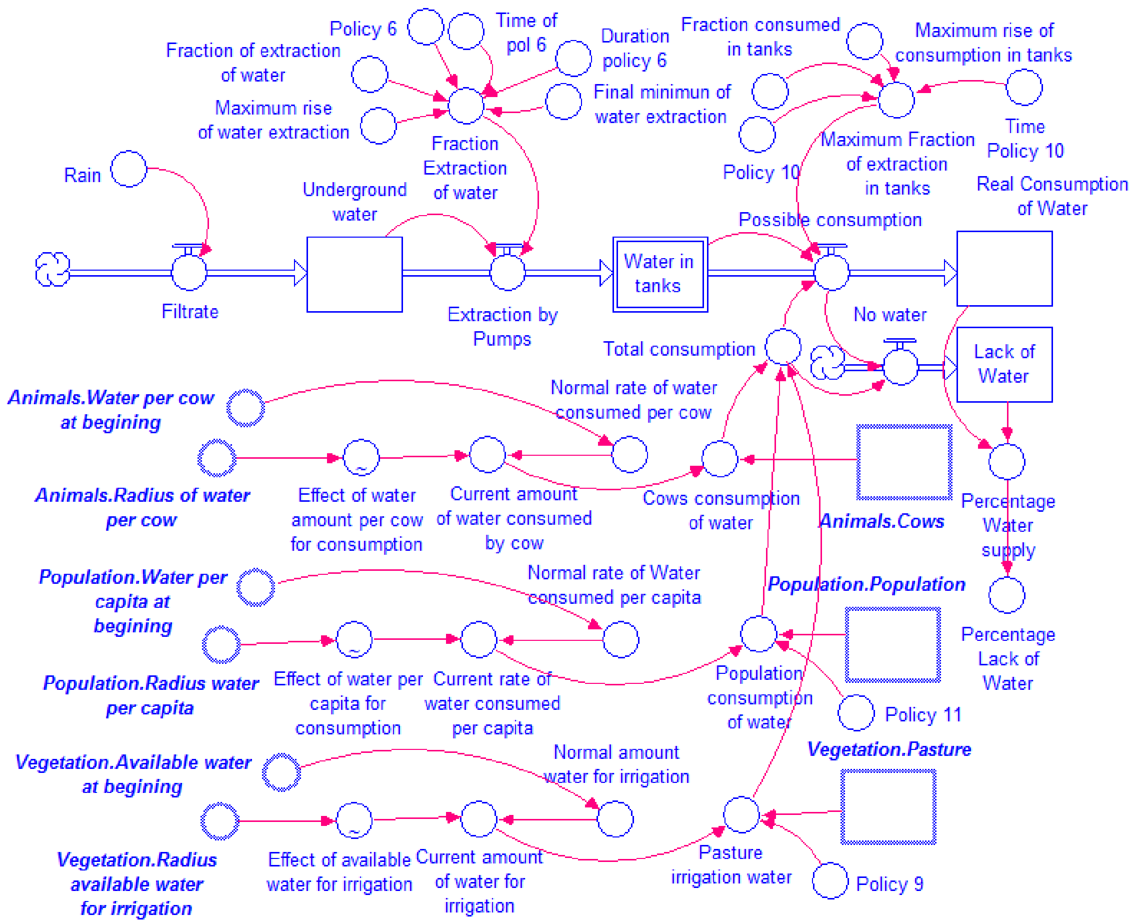
Description of the policy for the irrigation of vegetation.



Graph of the water effect available for the irrigation of pastures.



Complete model for the water dynamics.



Observations:

The complete model to simulate the water dynamics includes:

1. The dynamics of the water flow from the rain that falls, it is absorbed by the ground, then pumped to the ponds of the surface and consumed. The evaporation of a portion of the rain that falls on the surface, or what evaporates from the ponds in the day, is not included in the model to simplify it.
2. The policy to pump water from the wells to the ponds.
3. Policy to increase the water obtained from the ponds.
4. Policies to use the water besides the consumption of the living stock in the irrigated land and for human consumption.
5. The logic of calculation to determine the percentage of the water supply at all times.
6. The relationship cause-effect of the water supply with modules for animals, vegetation and human consumption.

Equations of the water model.

Lack_of__Water(t) = Lack_of__Water(t - dt) + (No_water) * dt
INIT Lack_of__Water = 0
INFLOWS:
No_water = if Total_consumption>Possible_consumption then Total_consumption-Possible_consumption else 0
Real_Consumption_of_Water(t) = Real_Consumption_of_Water(t - dt) + (Possible_consumption) * dt
INIT Real_Consumption_of_Water = 0
INFLOWS:
Possible_consumption = IF (Water_in_tanks*Maximum_Fraction_of_extraction_in_tanks>=Total_consumption) then Total_consumption else Water_in_tanks*Maximum_Fraction_of_extraction_in_tanks
Underground_water(t) = Underground_water(t - dt) + (Filtrate - Extraction_by_Pumps) * dt
INIT Underground_water = 500
INFLOWS:
Filtrate = Rain
OUTFLOWS:
Extraction_by_Pumps = (Underground_water*Fraction_Extraction_of_water)
Water_in_tanks(t) = Water_in_tanks(t - dt) + (Extraction_by_Pumps - Possible_consumption) * dt
INIT Water_in_tanks = 100
INFLOWS:
Extraction_by_Pumps = (Underground_water*Fraction_Extraction_of_water)
OUTFLOWS:
Possible_consumption = IF (Water_in_tanks*Maximum_Fraction_of_extraction_in_tanks>=Total_consumption) then Total_consumption else Water_in_tanks*Maximum_Fraction_of_extraction_in_tanks
Cows_consumption_of_water = Animals.Cows*Current_amount_of_water_consumed_by_cow
Current_amount_of_water_consumed_by_cow = Normal_rate_of_water_consumed_per_cow*Effect_of_water__amount_per_cow_for_consumption
Current_amount_of_water_for__irrigation = Normal_amount_water_for_irrigation*Effect_of_available_water_for_irrigation
Current_rate_of__water_consumed_per_capita = Normal_rate_of_Water_consumed_per_capita*Effect_of_water_per_capita_for_consumption
Duration_policy_6 = 18
Final_minimun_of_water_extraction = 0.0
Fraction_consumed_in_tanks = 0.80
Fraction_Extraction_of_water = if (Policy_6=1) then Fraction_of_extraction_of_water+ STEP(Maximum_rise__of_water_extraction,Time_of_pol_6)- STEP(Final_minimun_of_water_extraction,Duration_policy_6+Time_of_pol_6) else Fraction_of_extraction_of_water
Fraction_of_extraction_of_water = 0.20
Maximum_Fraction_of_extraction_in_tanks = if Policy_10=1 then
 if Fraction_consumed_in_tanks+ Maximum_rise_of__consumption_in_tanks>=1 then 1
 else Fraction_consumed_in_tanks+ Step(Maximum_rise_of__consumption_in_tanks, Time_Policy_10)
else Fraction_consumed_in_tanks

Maximum_rise_of__consumption_in_tanks = 0.20
Maximum_rise__of_water_extraction = 0.20
Normal_amount_water_for_irrigation = Vegetation.Available_water_at_begining
Normal_rate_of_Water_consumed_per_capita = Population.Water_per_capita_at_begining
Normal_rate_of_water_consumed_per_cow = Animals.Water_per_cow__at_begining
Pasture_irrigation_water = if (Policy_9=1) then Vegetation.Pasture*Current_amount_of_water_for__irrigation else 0
Percentage_Lack_of_Water = if Percentage_Water_supply=0 then 0 else 100-Percentage_Water_supply
Percentage_Water_supply = if (Real_Consumption_of_Water+Lack_of__Water)=0 then 0
else Real_Consumption_of_Water/(Real_Consumption_of_Water+Lack_of__Water)*100
Policy_10 = 1

Policy_11 = 1

Policy_6 = 1

Policy_9 = 0

Population_consumption_of_water = if Policy_11=1 then Population.Population*Current_rate_of__water_consumed_per_capita else 0

Rain = 100+0*NORMAL(1,.1)

Time_of_pol_6 = 2

Time_Policy_10 = 2

Total_consumption = Pasture_irrigation_water+Population_consumption_of_water+Cows_consumption_of_water

Effect_of_available_water_for_irrigation = GRAPH(Vegetation.Radius_available_water__for_irrigation)

(0.00, 0.00), (0.2, 0.27), (0.4, 0.51), (0.6, 0.713), (0.8, 0.87), (1.00, 1.00), (1.20, 1.10), (1.40, 1.19), (1.60, 1.25), (1.80, 1.28), (2.00, 1.30)

Effect_of_water_per_capita_for_consumption = GRAPH(Population.Radius_water_per_capita)

(0.00, 0.00), (0.2, 0.27), (0.4, 0.51), (0.6, 0.713), (0.8, 0.87), (1.00, 1.00), (1.20, 1.10), (1.40, 1.19), (1.60, 1.25), (1.80, 1.28), (2.00, 1.30)

Effect_of_water__amount_per_cow_for_consumption = GRAPH(Animals.Radius_of_water_per_cow)

(0.00, 0.00), (0.2, 0.27), (0.4, 0.51), (0.6, 0.713), (0.8, 0.87), (1.00, 1.00), (1.20, 1.10), (1.40, 1.19), (1.60, 1.25), (1.80, 1.28), (2.00, 1.30)

Sahel learning lab