



# Sahel Learning Lab.

## Supporting Materials

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### 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**

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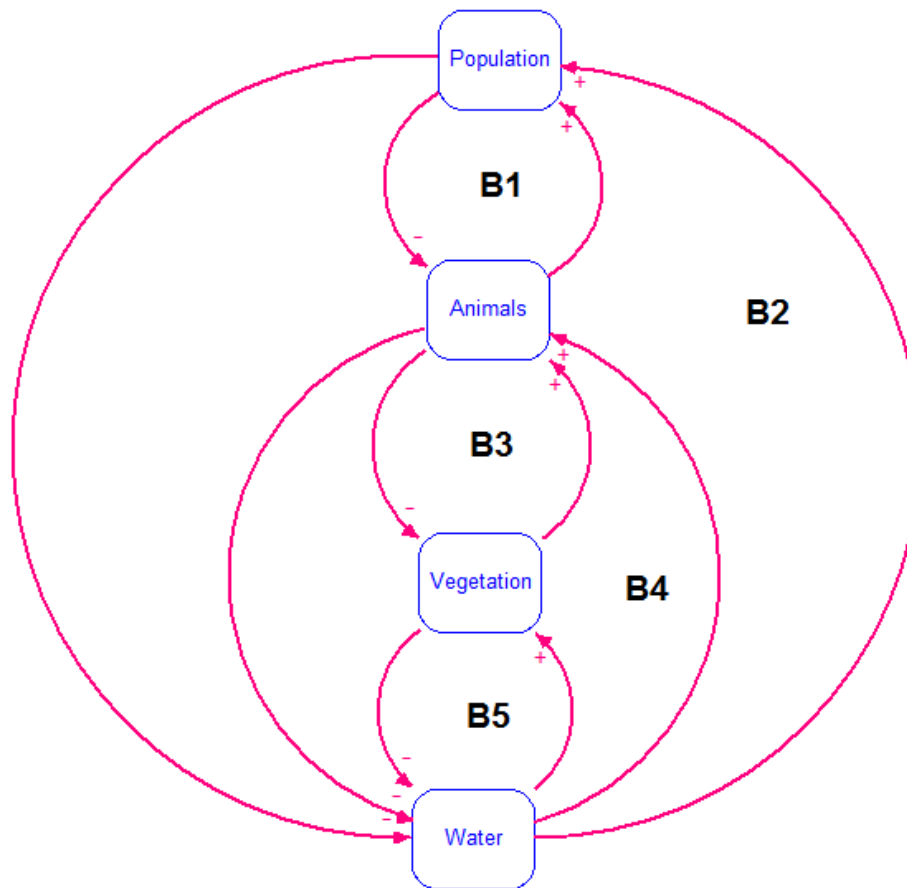
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## Sahel – System Modules



### Development model step by step.

#### Modeling a sustainable lifestyle.

In this occasion, we've developed a complete business 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 exploitation 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.

**Policies to improve the genetic of animals and increase the production of beef and milk products.**

The illnesses in the animals were also controled and genetic improvements in the herds were introduced to increase the production of milk product, its rate of reproduction and production of beef.

Policy 3: To decrease the waste.	
Animals.Normal Fr of cows waste	0.1
Animals.FR Decrease of cows waste	0.02
Animals.Time pol 3	2

Effect of water availability, in rates of: (Growth and Death)

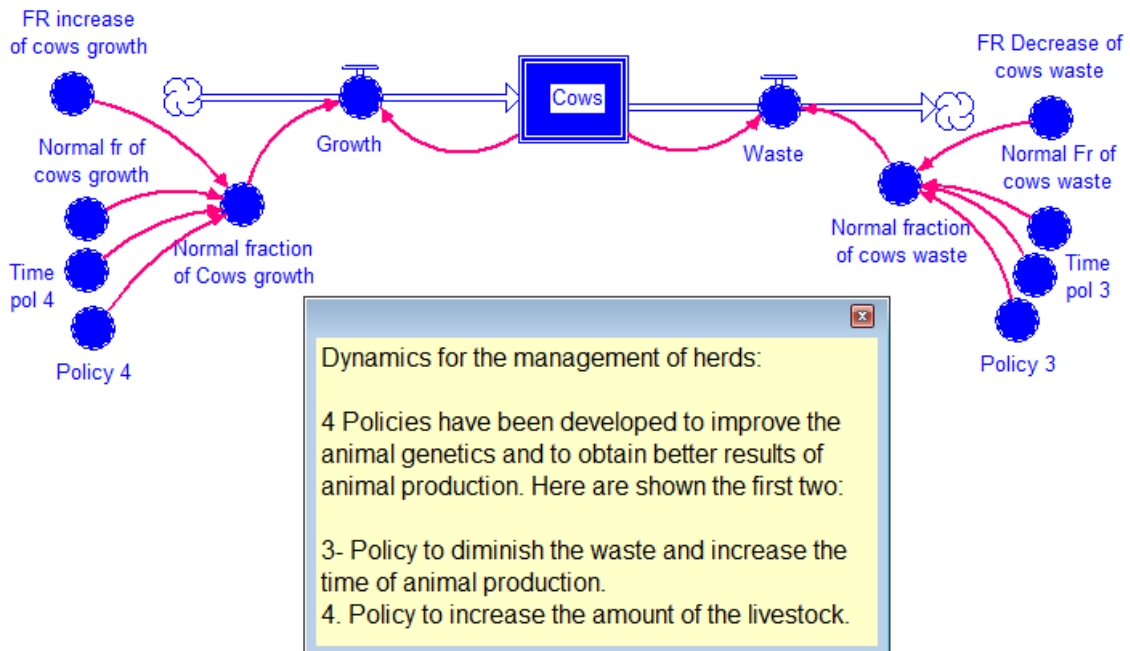
Effect cows per capita, in consumption:

Effect in the availability of pasture, in rates of: (Growth and Death)

Modules of the Sahel

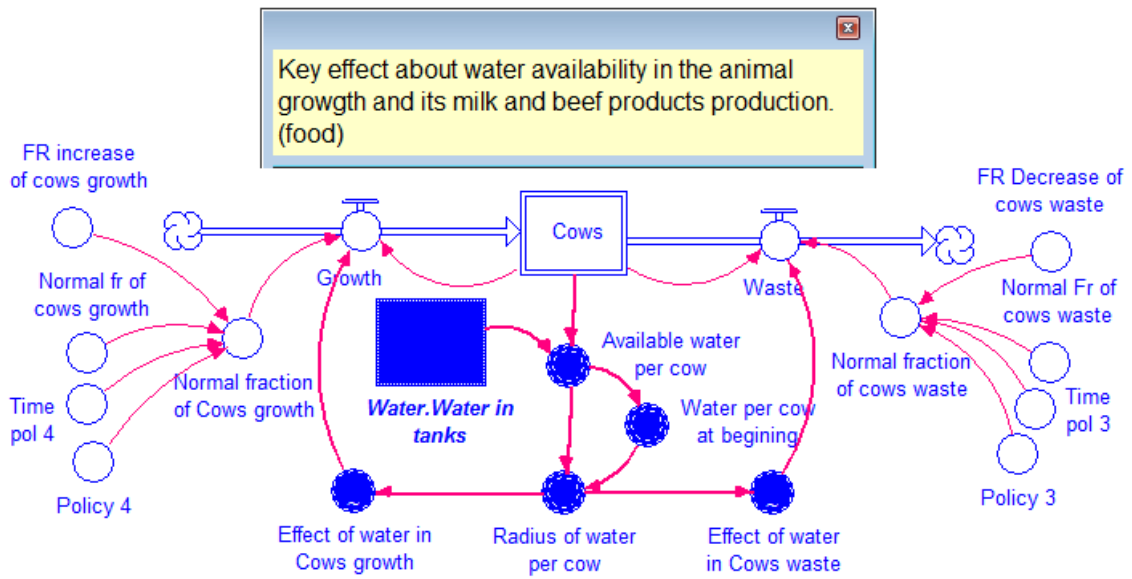
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Dynamics for the management of the herds of animals.

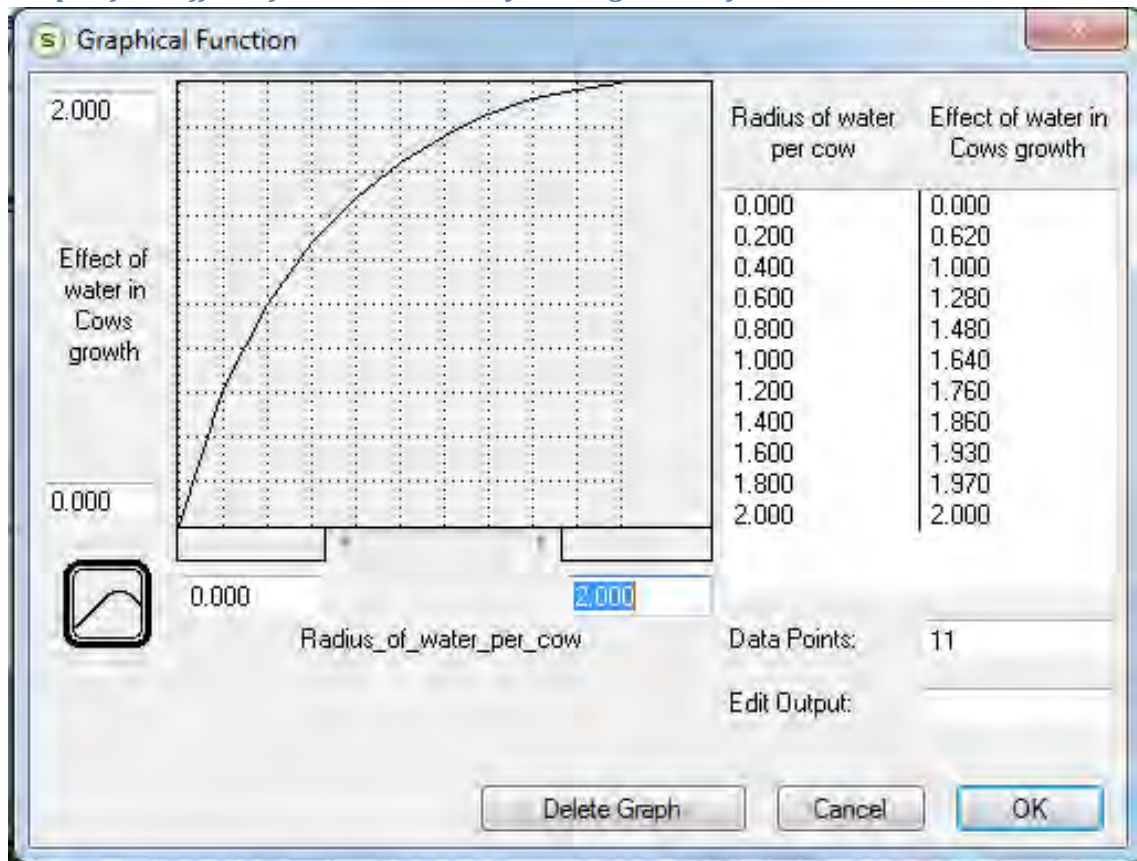


SAHEL – Modeling a sustainable lifestyle

Effect of water availability in the growth of herds.



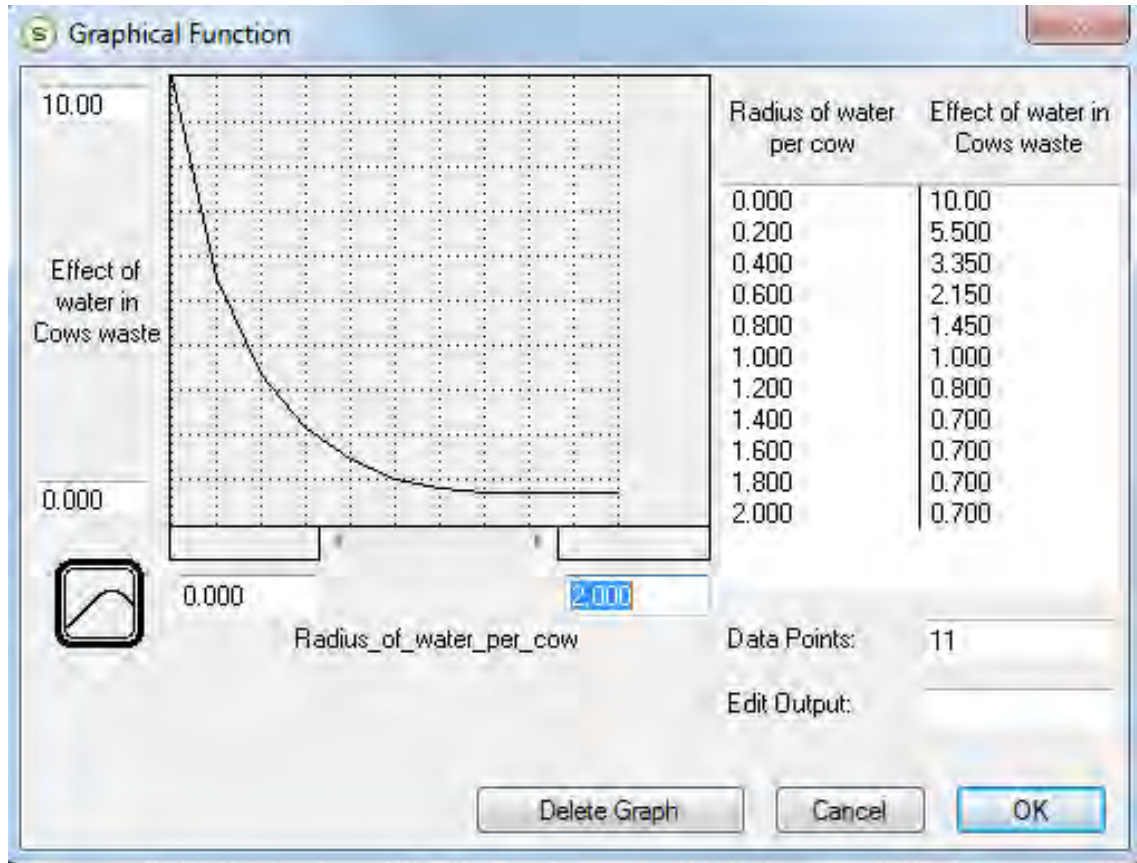
Graph of the effect of water availability in the growth of cows.



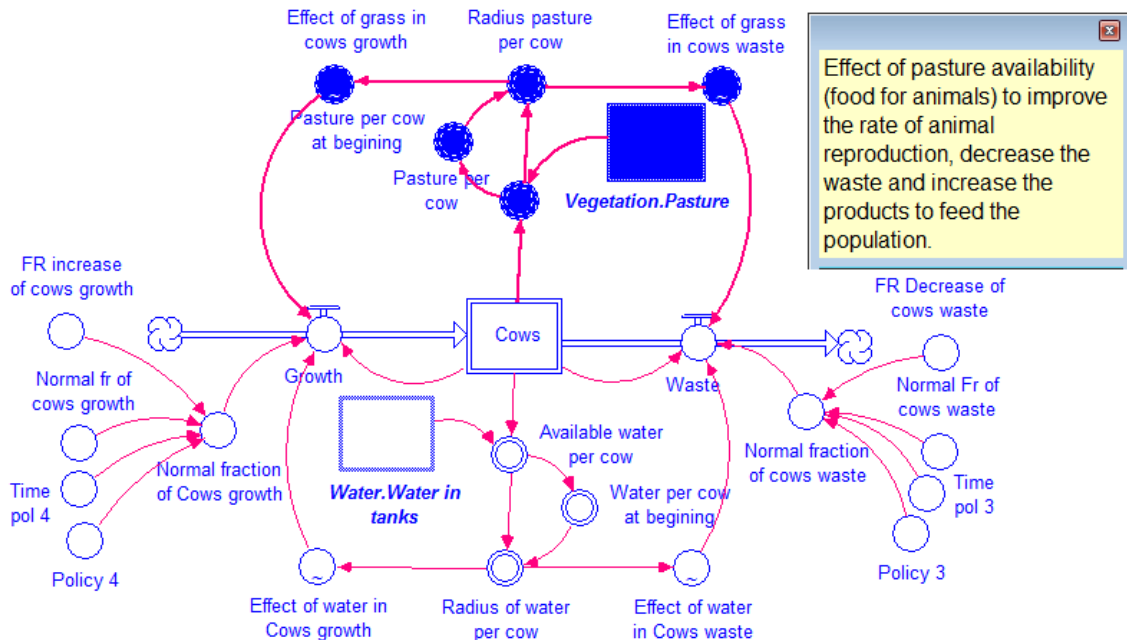
When the radius of water per cow is greater than 1, the cows' normal fraction of growth increases, if it is less than 1, the opposite occurs.

SAHEL – Modeling a sustainable lifestyle

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



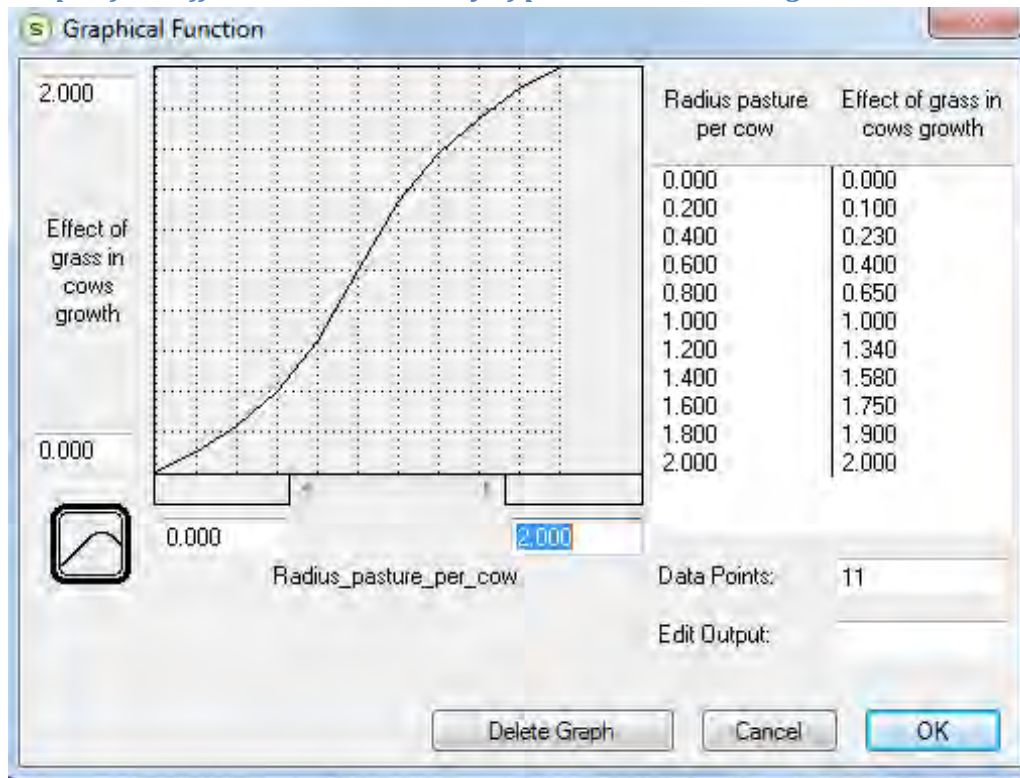
Effect of the availability of pasture in the animal growth.



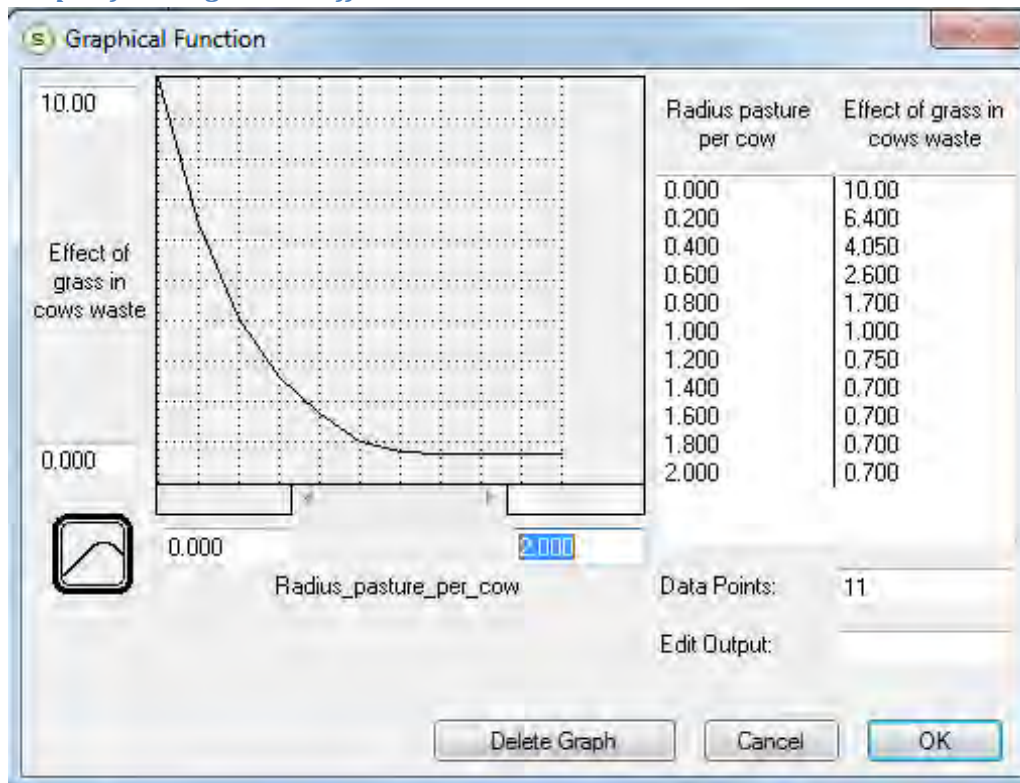


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Graph of the effect in the availability of pasture in the cows growth.

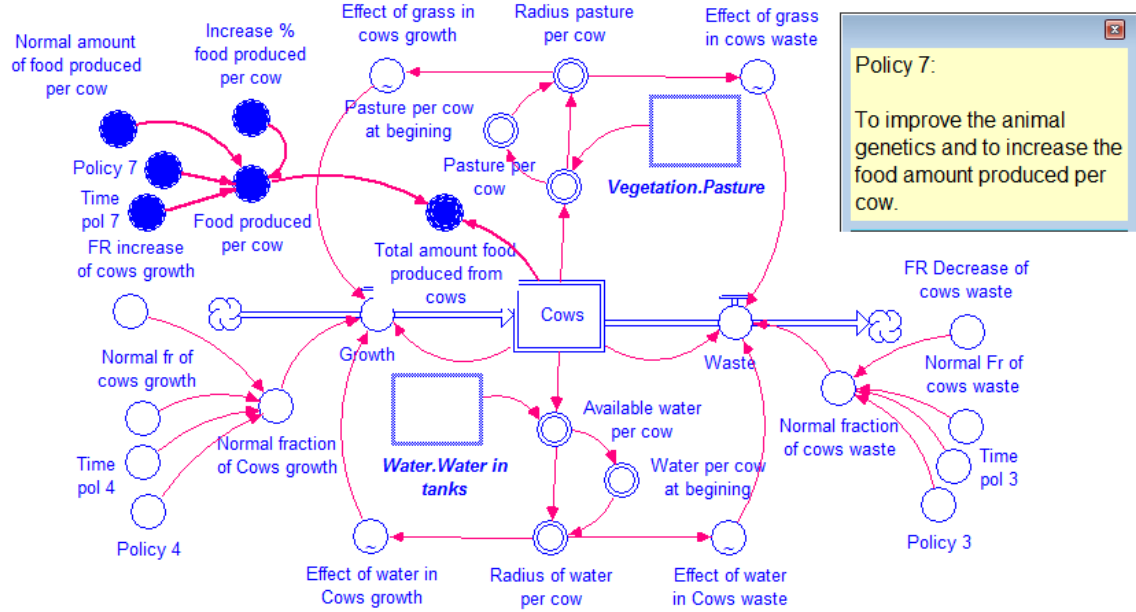


Graph of the vegetation effect in the cows' waste.

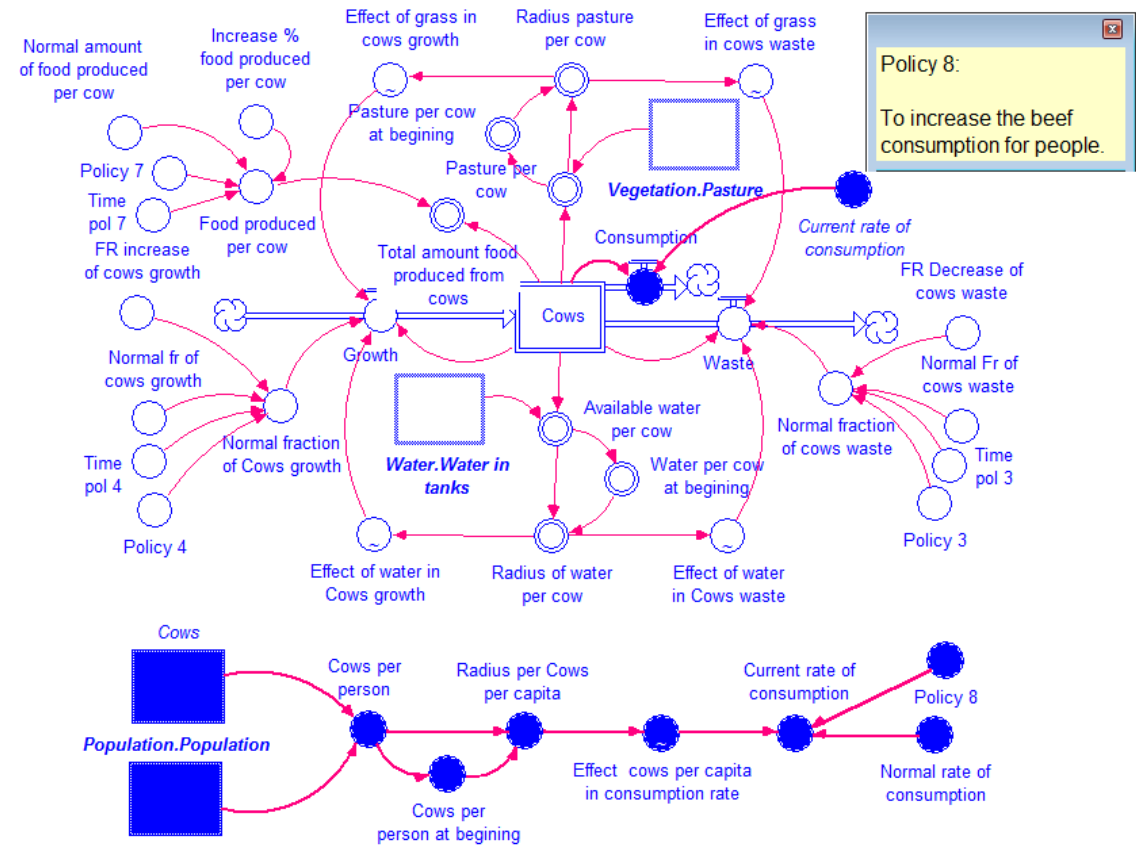


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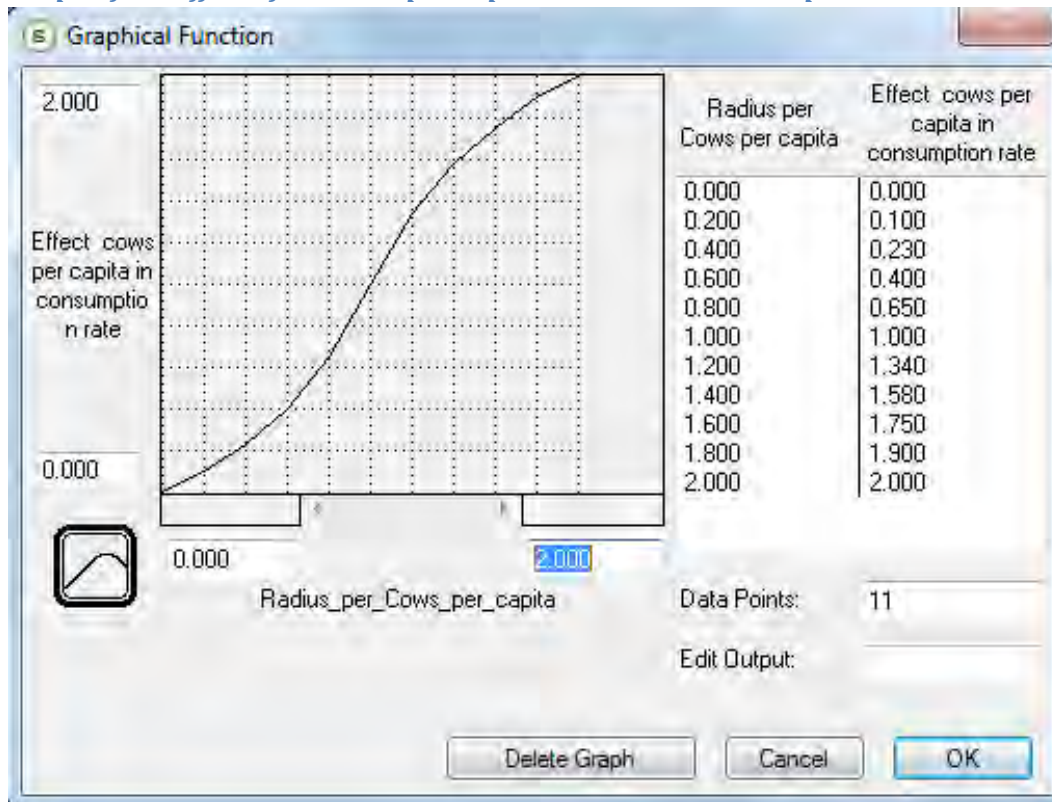
Genetic improvement of animals to increase the milk and meat production.



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**

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

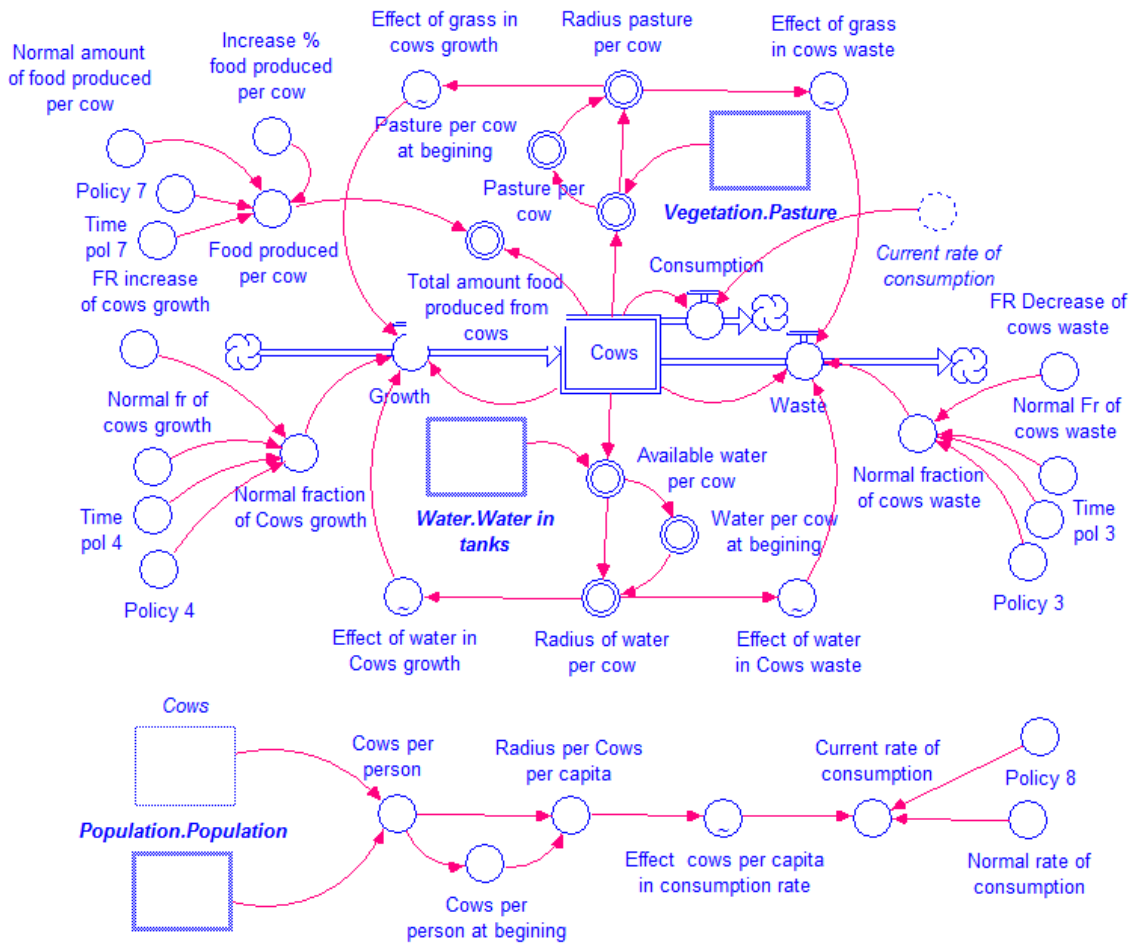
1. When the radius of cows per capita is greater than 1, the normal rate of consumption increases by a factor obtained in the graph.
2. When the radius is 1, then the normal rate of consumption stays the same.
3. For radius of cows per capita is less than 1, the normal rate of consumption will be reduced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

SAHEL – Modeling a sustainable lifestyle

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)

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Other policies and initial 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.

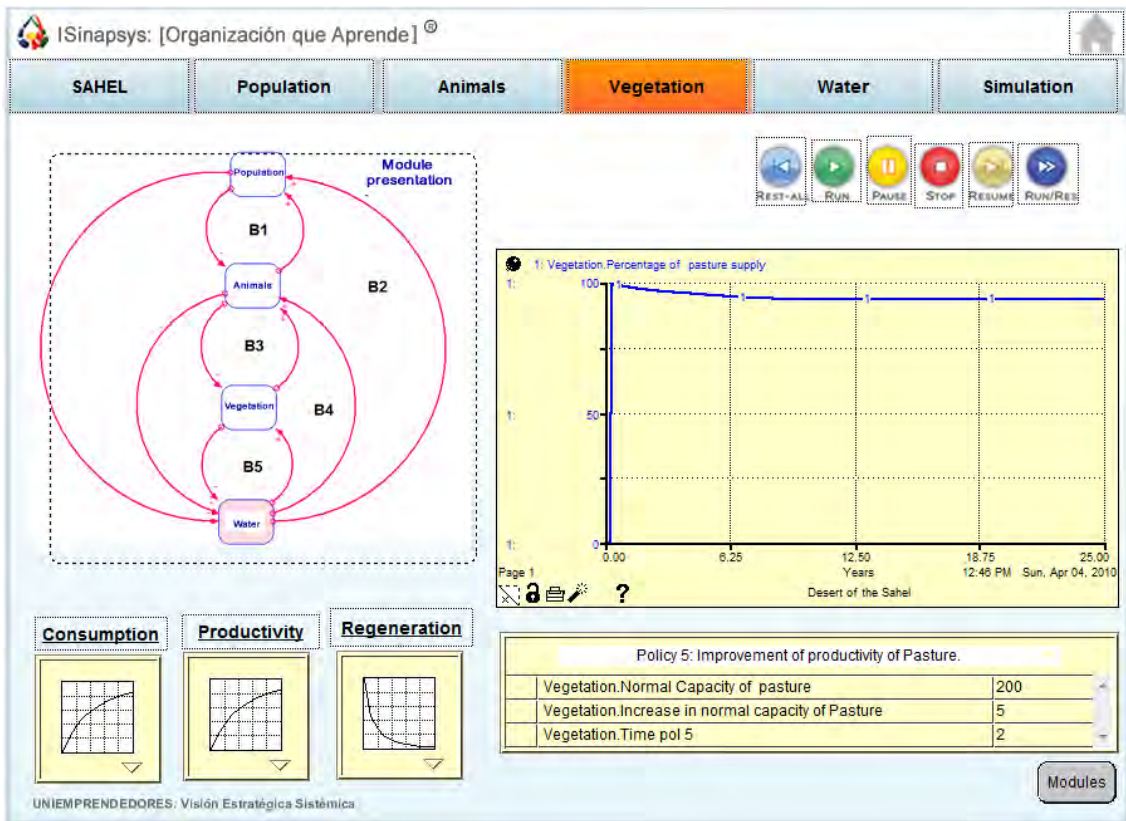
All of them are involved in the genetic improvement of the animals to increase the productivity of their products, improve their reproductive capacity and reduce the natural waste.

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 castrated as condemned animal material.

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

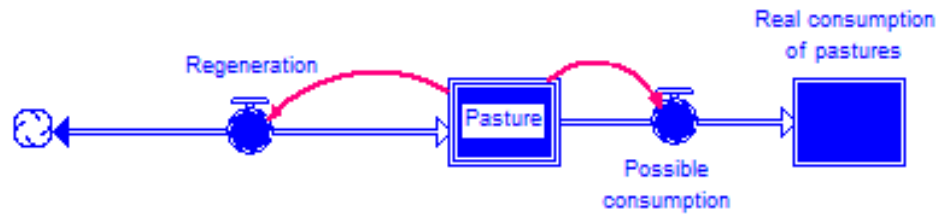
1. The water availability in the surface ponds.
2. The quality of produced grass.

Module for vegetation.



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

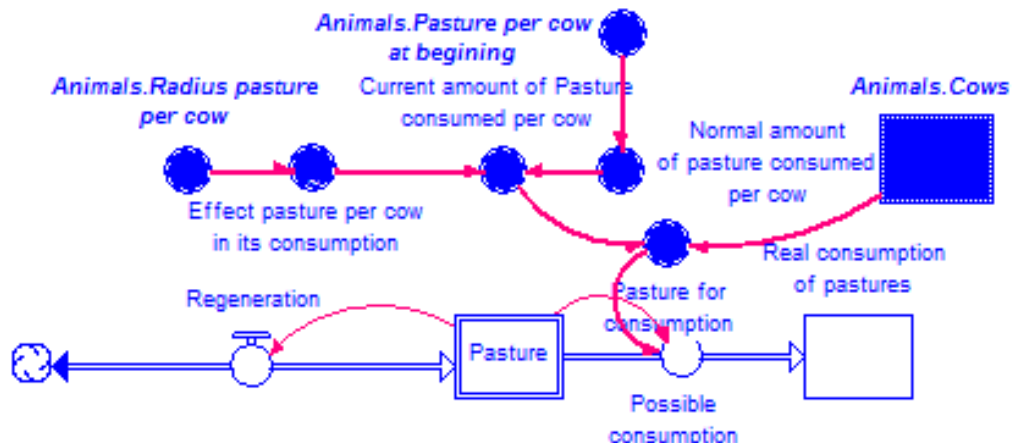
Dynamics for the vegetation management.



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 until rise to a maximum biological limit consumption per animal.



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

ISinapsys: [Organización que Aprende] ©

SAHEL Population Animals **Vegetation** Water Simulation

Module presentation

REST-ALL RUN PAUSE STOP RESUME RUN/RES

1: Vegetation: Percentage of pasture supply

Pasture effect per cow in its consumption.

Base don the available pasture per cow, this graphic links the pasture availability with its consumption per cow. If there is enough pasture, the cow will consume more untill rise to a maximum biological limit. If there is less grass, it will be divided between the quantity of animals with the consequent deterioration in its milk and beef production for human consumption and sale items.

0 50 100

0.00 6.25 12.50 18.75 25.00

Years 12:48 PM Sun, Apr 04, 2010

Desert of the Sahel

Consumption Productivity Regeneration

Policy 5: Improvement of productivity of Pasture.

Vegetation.Normal Capacity of pasture	200
Vegetation.Increase in normal capacity of Pasture	5
Vegetation.Time pol 5	2

Modules

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

Graphical Function

Effect pasture per cow in its consumption

Animals.Radius\_pasture\_per\_cow

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

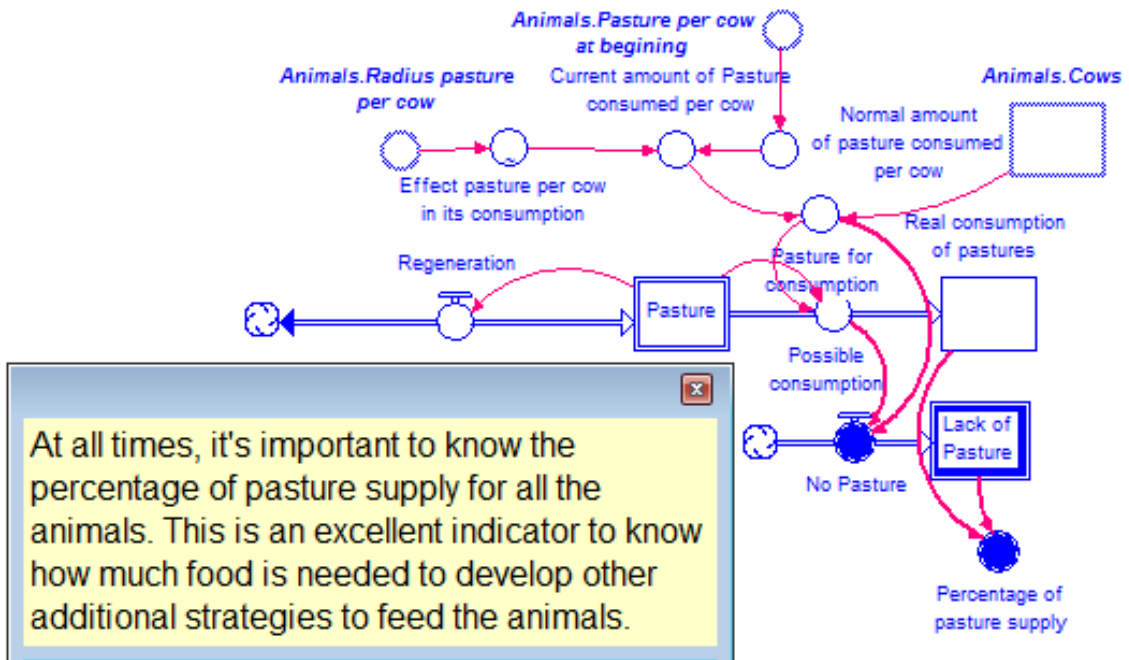
Data Points: 11

Edit Output:

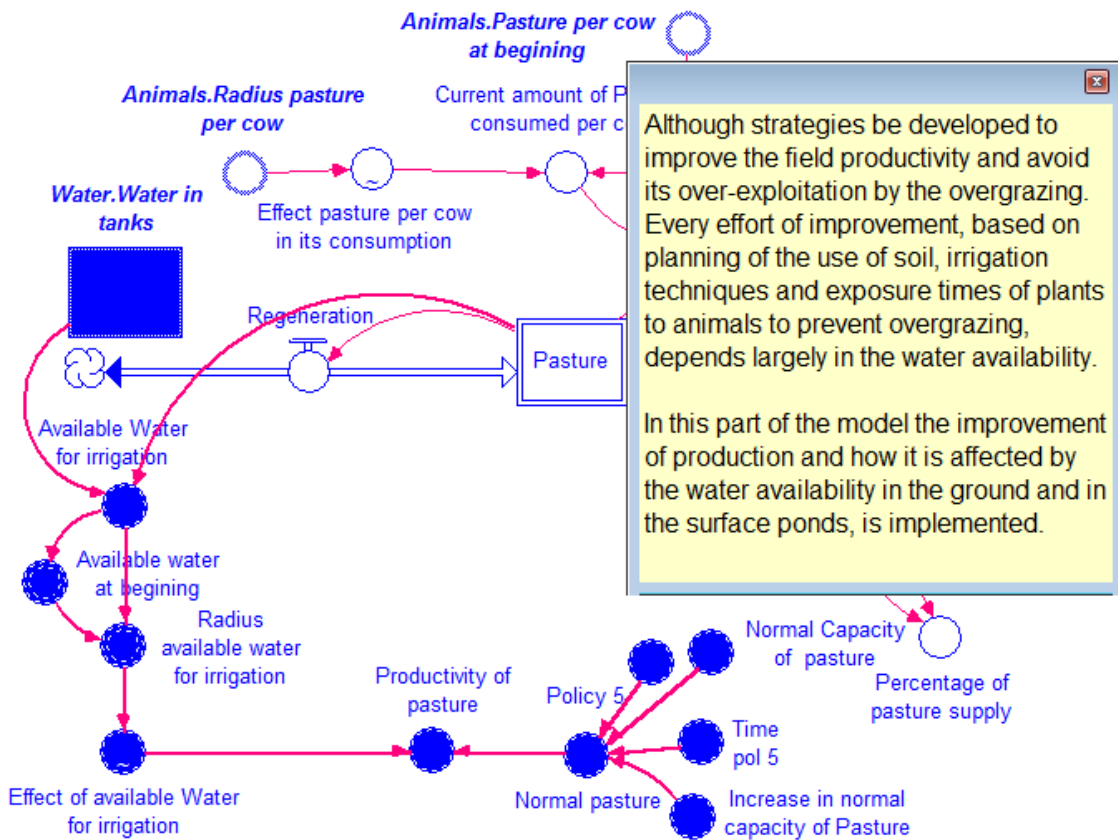
Delete Graph Cancel OK

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Percentage indicator for the pasture supply.



Effect of the water availability in the field productivity.



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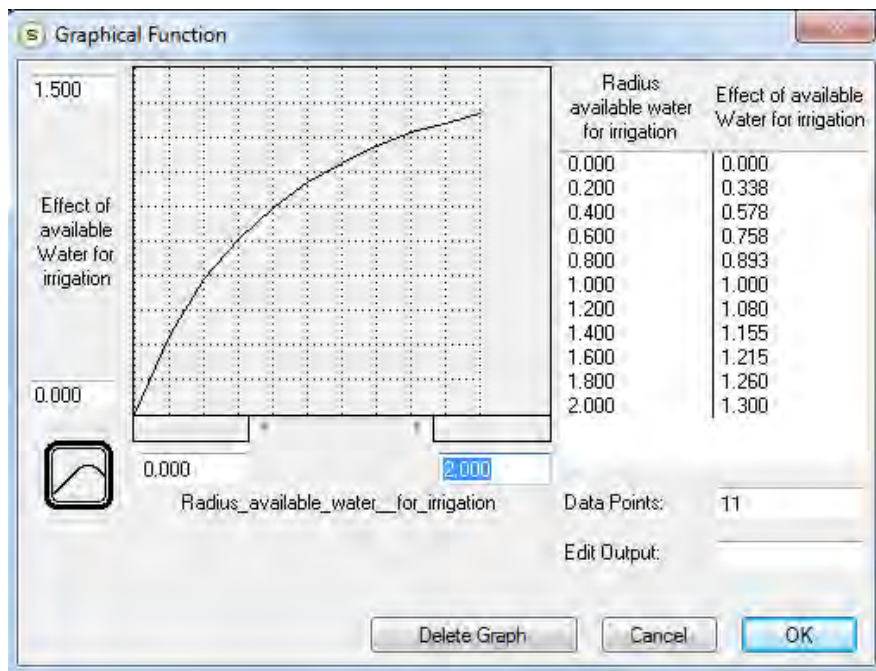
Description of the water effect in the productivity of pasture.

Water availability effect in the productivity of vegetation:

Depending on the water availability of rain or the use of water from the ponds of the surface to irrigate the vegetation if there is enough water. This graphic links the change of productivity in the field due to the use of water and its impact in the natural regeneration of pasture.

Policy 5: Improvement of productivity of Pasture.	
Vegetation.Normal Capacity of pasture	200
Vegetation.Increase in normal capacity of Pasture	5
Vegetation.Time pol 5	2

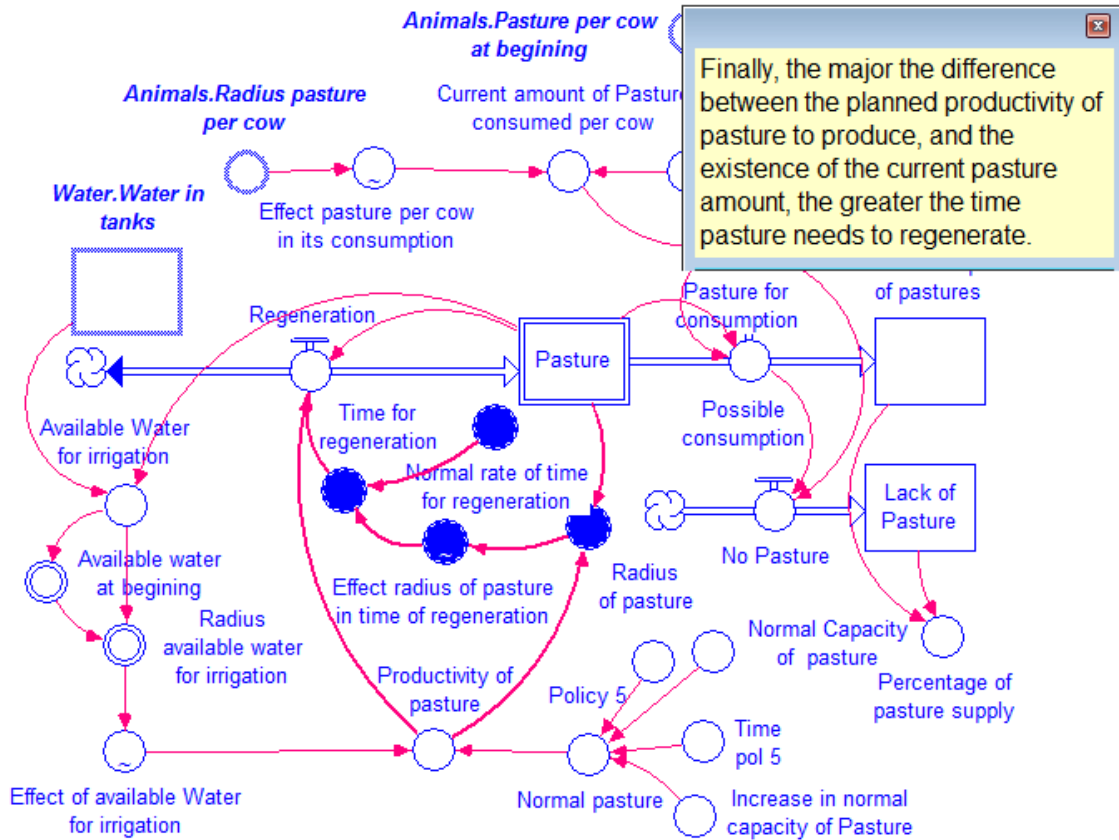
Graph of the effect in the availability of water for the pasture productivity.





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Effect of the pasture productivity on its regenerative time.



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

Sinapsys: [Organización que Aprende]®

SAHEL | Population | Animals | **Vegetation** | Water | Simulation

Module presentation

Effect of pasture productivity in the time of its natural regeneration:

Based in the water availability and a better care of the pasture cultivation, this graphic links how an increasing or decreasing of its productivity provoques an impact in the time of natural regeneration of the grass.

The major the productivity, if the current radius of grass and the production quantity of grass is less than one, the major the time it will need to regenerate and produce the additional grass.

Percentage of pasture supply

0.00 6.25 12.50 18.75 25.00  
Years  
12:46 PM Sun, Apr 04, 2010  
Desert of the Sahel

Consumption | Productivity | Regeneration

Policy 5: Improvement of productivity of Pasture.

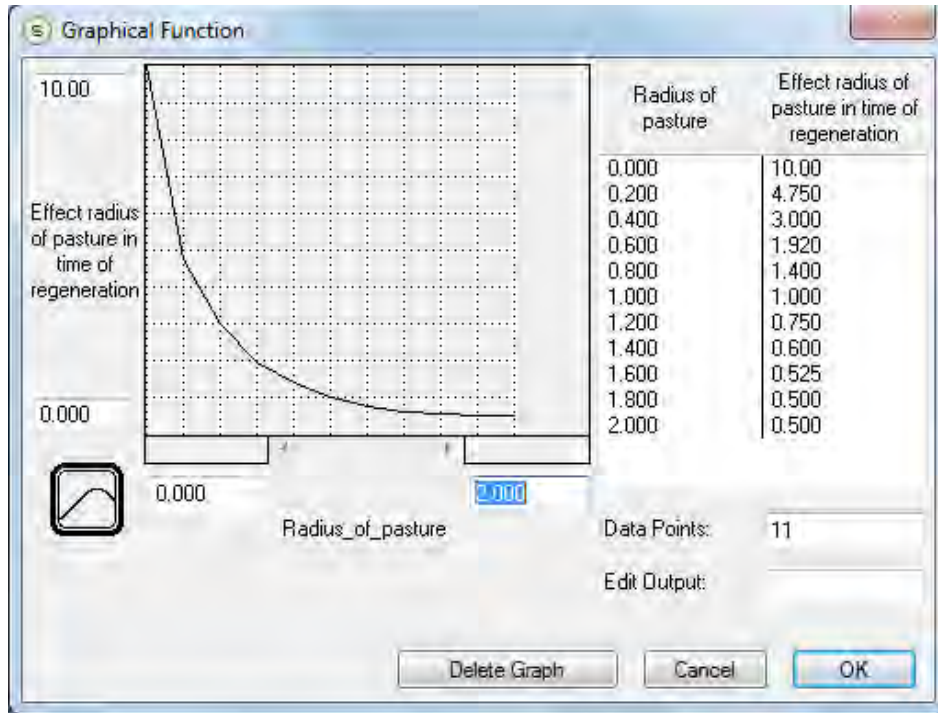
Vegetation.Normal Capacity of pasture	200
Vegetation.Increase in normal capacity of Pasture	5
Vegetation.Time pol 5	2

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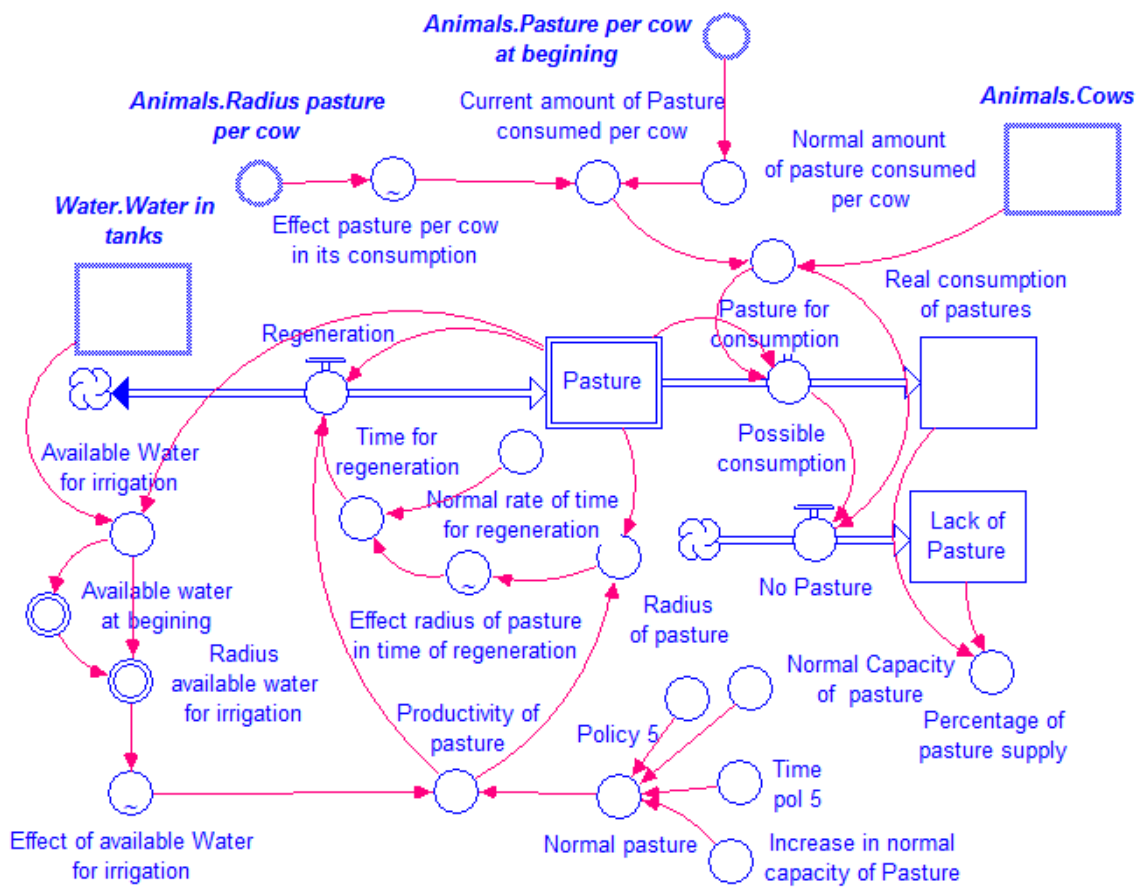
Modules

SAHEL – Modeling a sustainable lifestyle

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

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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.

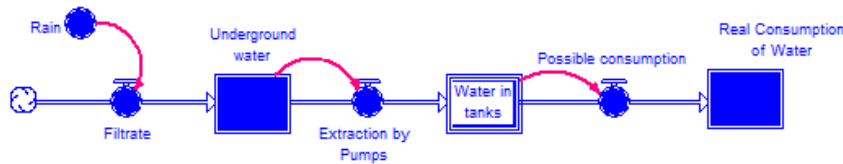
This is closely related to the water availability, any strategy to improve the plantation of grasses, including take a great care of overgrazing, can be implemented, but anyone will work without water.

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.

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



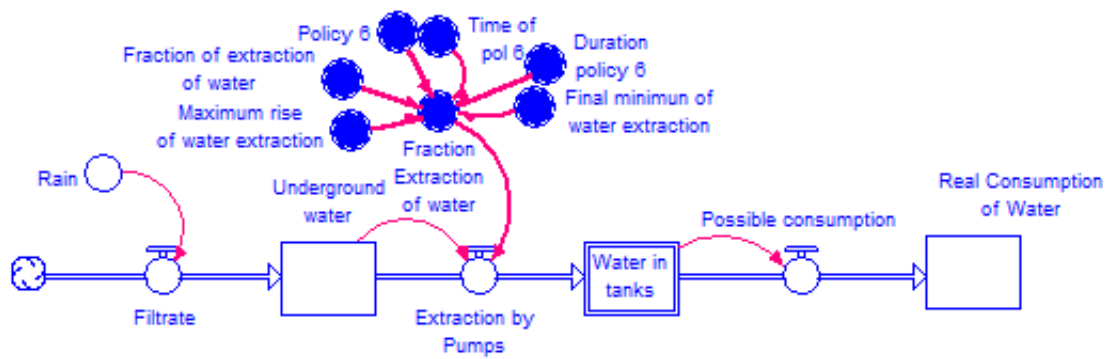
System dynamics to simulate the behavior of the water flow that follows the following steps:

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 amount of rainfall evaporates, the evaporation logic is omitted to simplify the model.

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

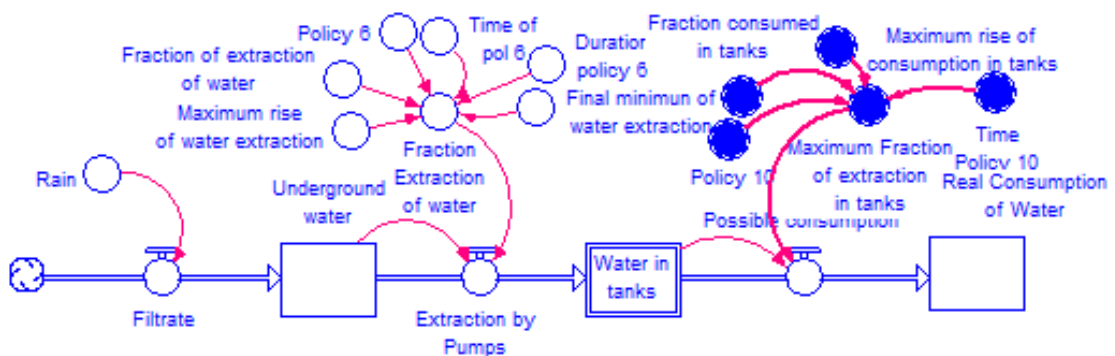
Pumping water from deep wells to surface ponds.



**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.



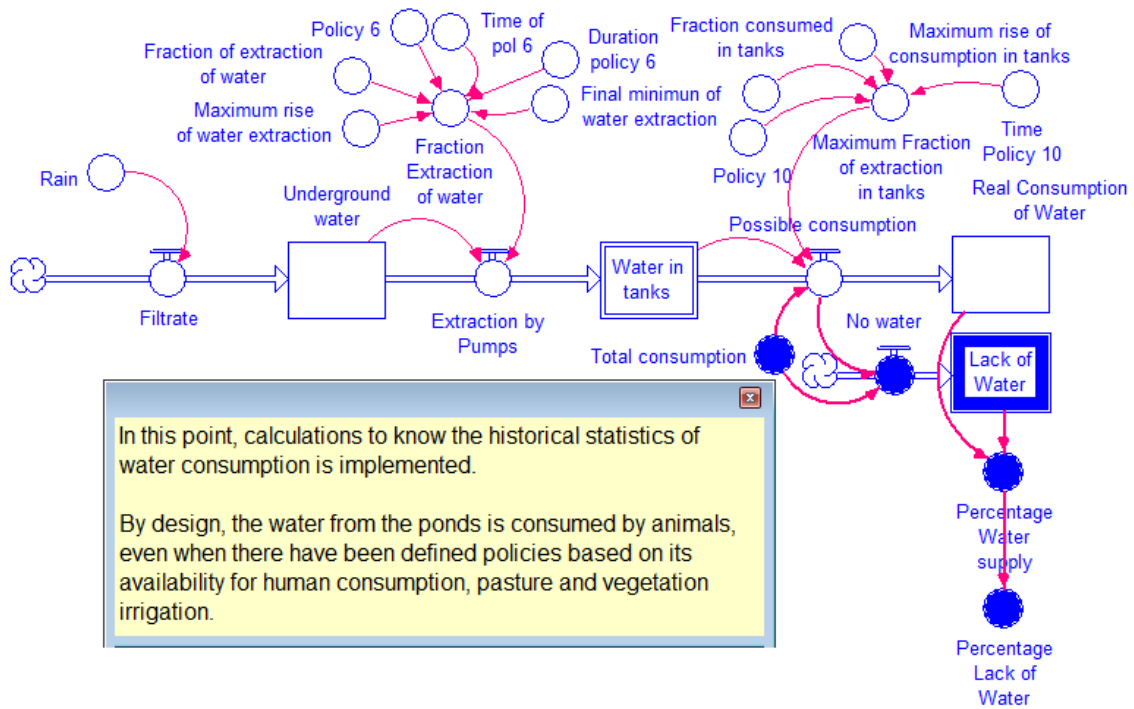
**Policy 10: To manage the use of water consumed in the ponds:**

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

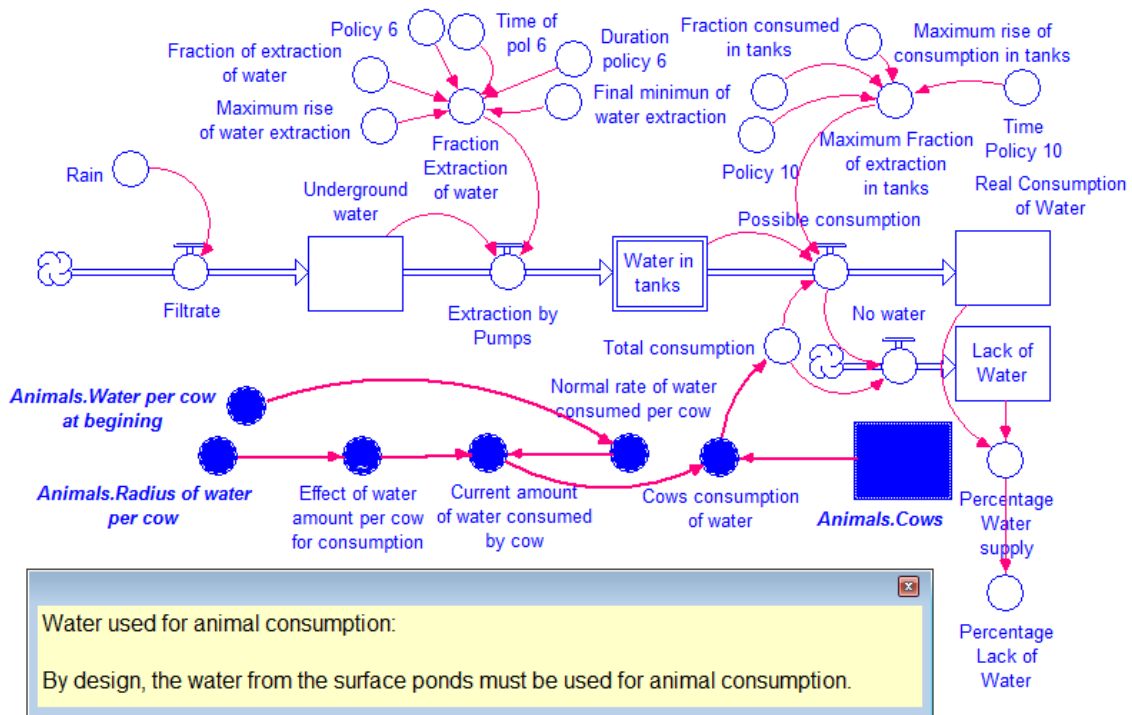
The water from ponds of the surface is commonly used for animal consumption. Two additional policies have been developed, based on the vital liquid availability, through those policies it's possible to use the water for human consumption and also to water the pastures as a complement to the rainwater (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.

SAHEL – Modeling a sustainable lifestyle

Statistical history of water consumption.



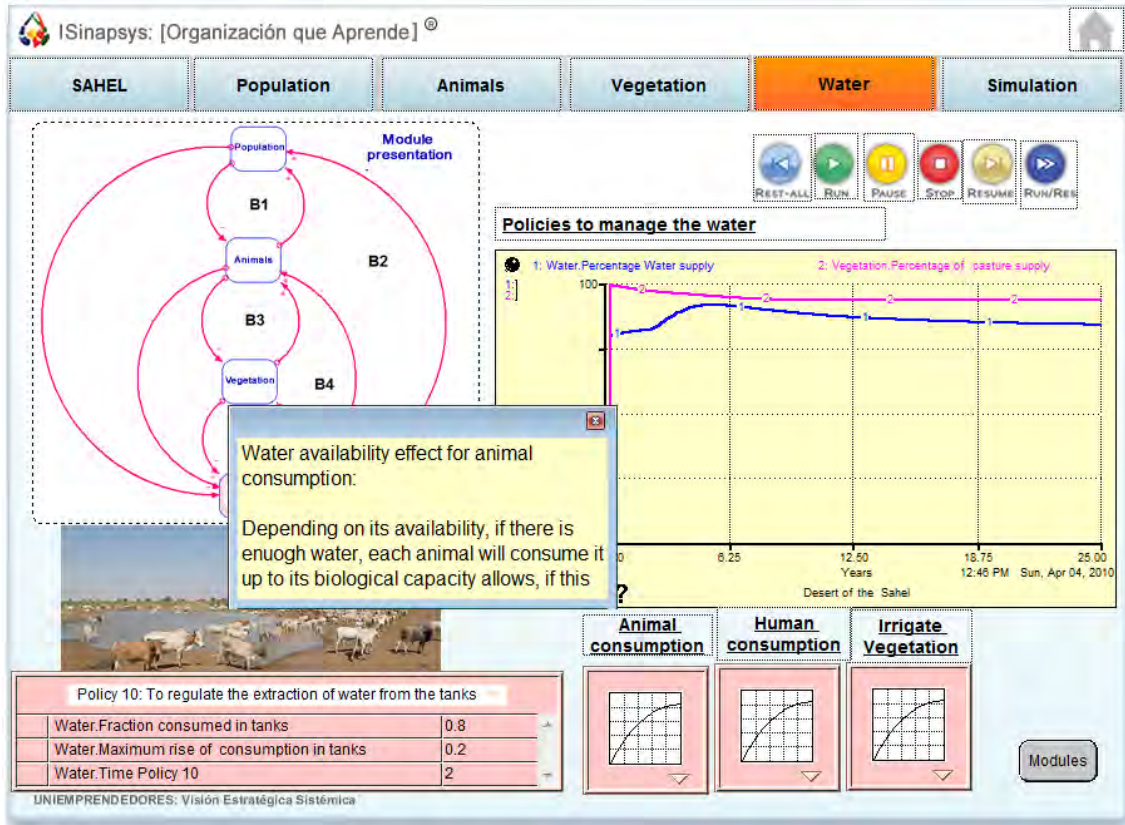
Water used for animal consumption.



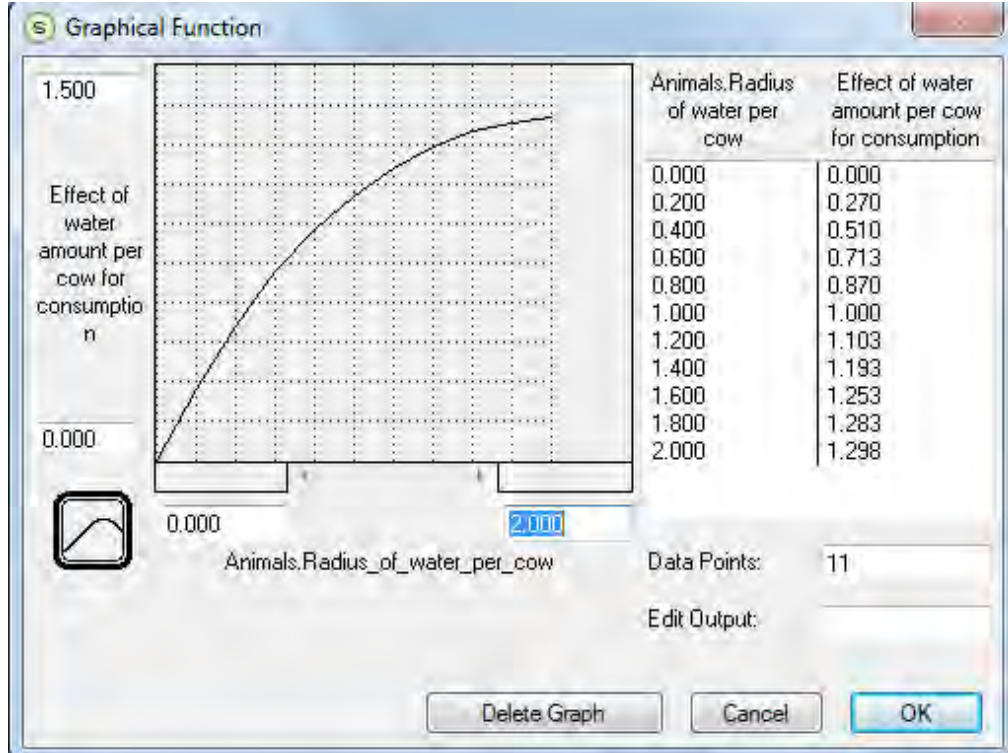


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Description of the effect in the water availability for the animal consumption.

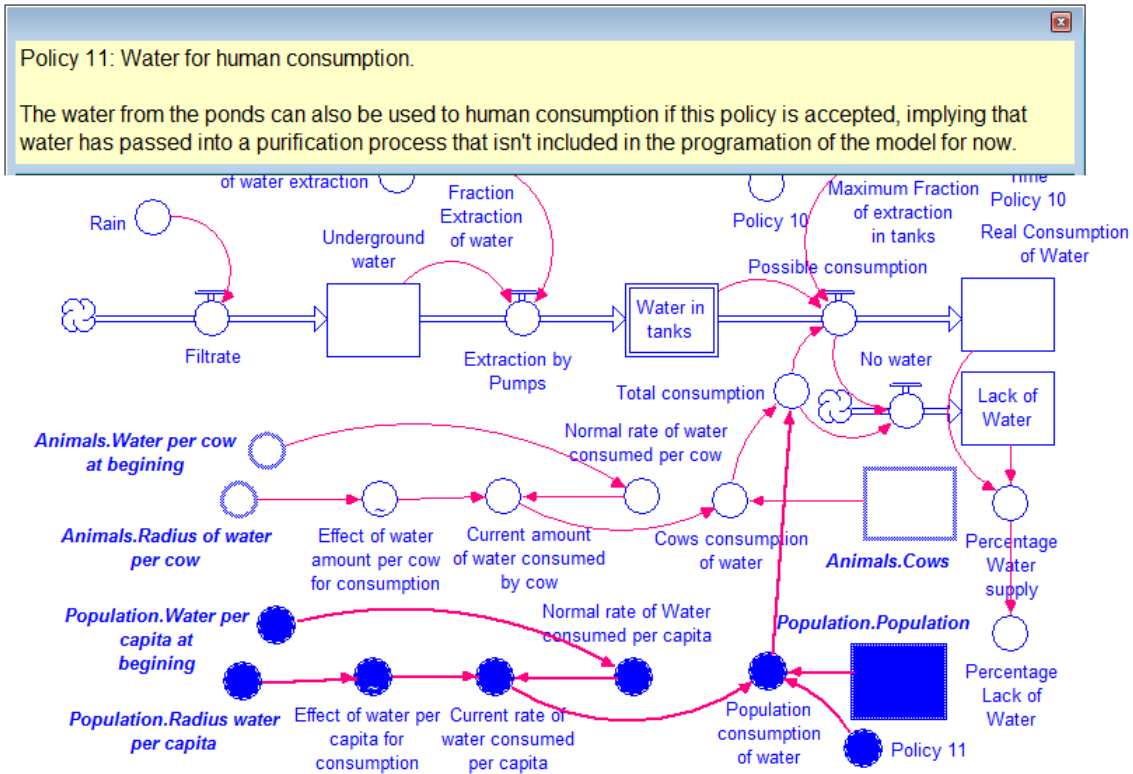


Graph of the water effect per cow by the animal consumption.



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Water policy for human consumption.



Policy description for water use for human consumption.

ISinapsys: [Organización que Aprende] ©

SAHEL | Population | Animals | Vegetation | **Water** | Simulation

Module presentation: Population (B1), Animals (B2), Vegetation (B3, B4)

Policies to manage the water:

- 1: Water.Percentage Water supply
- 2: Vegetation.Percentage of pasture supply

Water availability effect for human consumption:

If there is available water, and assuming that it must have a purification process (not contemplated in this model), if this policy is accepted, the water from the ponds could be used for human consumption.

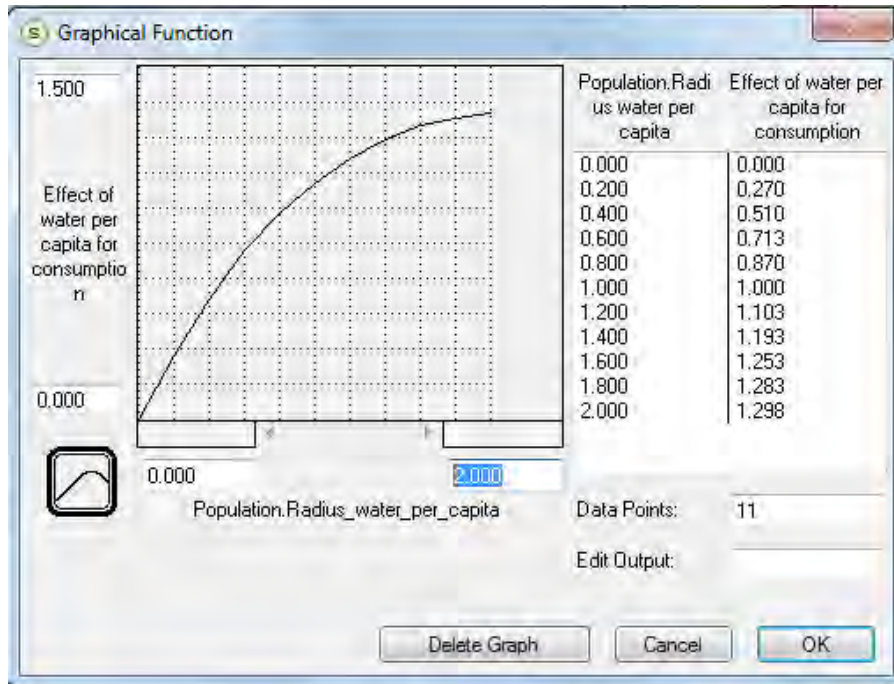
Policy 10: To regulate the extraction of water from the tanks	
Water.Fraction consumed in tanks	0.8
Water.Maximum rise of consumption in tanks	0.2
Water.Time Policy 10	2

Animal consumption | Human consumption | Irrigate Vegetation

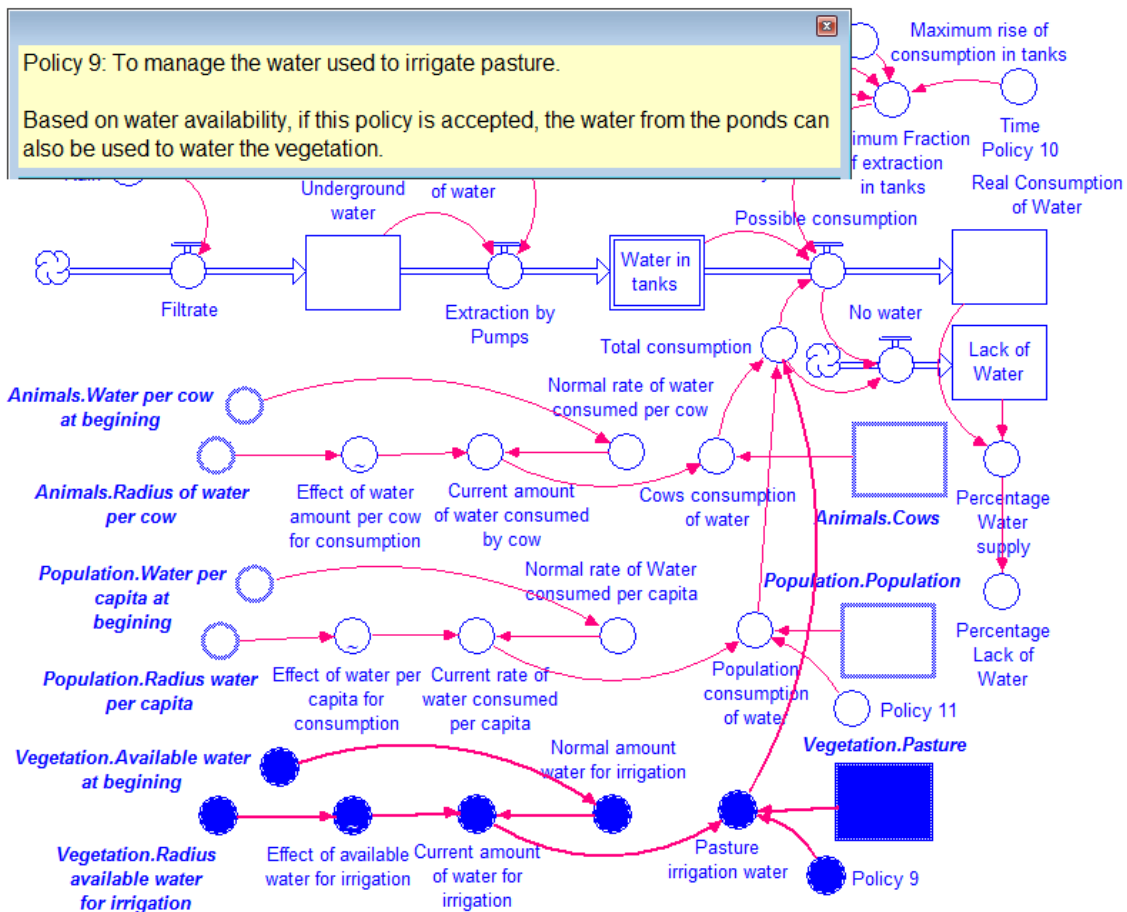
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Graph of the water effect per capita for human consumption.



Policy for water use for irrigation of vegetation.





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Description of the policy for the irrigation of vegetation.

The screenshot shows the SAHEL simulation software interface. At the top, there are tabs for SAHEL, Population, Animals, Vegetation, Water, and Simulation. The 'Water' tab is selected. On the left, a system dynamics model is shown with nodes for Population, Animals, and Vegetation, connected by causal links labeled B1, B2, and B3. A 'Module presentation' box is overlaid on the model, containing text about water availability for irrigation. In the center, a graph titled 'Policies to manage the water' shows two data series: '1: Water.Percentage Water supply' and '2: Vegetation.Percentage of pasture supply'. Below the graph, there are three small graphs for 'Animal consumption', 'Human consumption', and 'Irrigate Vegetation'. At the bottom left, a table for 'Policy 10: To regulate the extraction of water from the tanks' is visible.

**Effect of the water availability to irrigate the pasture:**

Vegetation in a desertic environment, commonly is only watered during the rainy season, usually the water stored in the surface ponds is only used for animal and/or human consumption.

Only in special cases when there is enough water, we can think in the implementation of this policy of pastures irrigation with water from the ponds.

Policy 10: To regulate the extraction of water from the tanks	
Water.Fraction consumed in tanks	0.8
Water.Maximum rise of consumption in tanks	0.2
Water.Time Policy 10	2

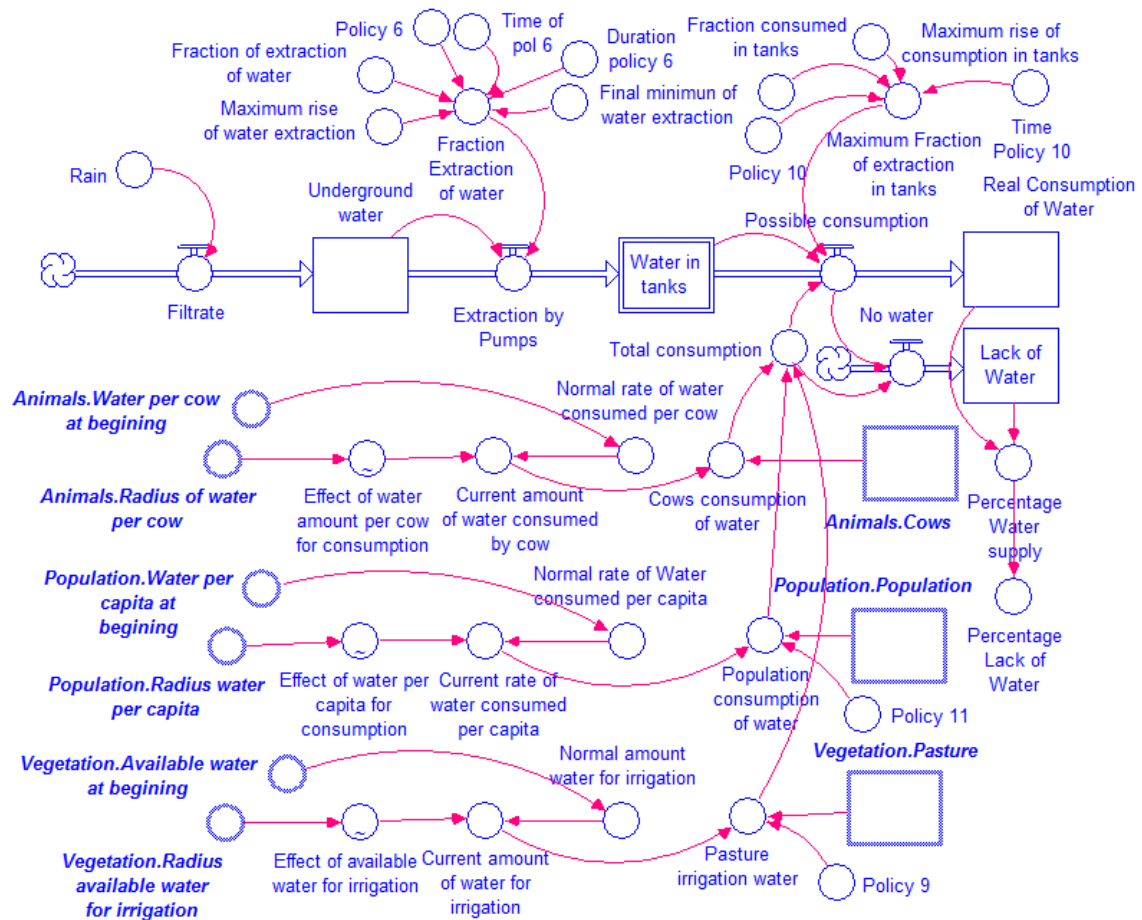
Graph of the water effect available for the irrigation of pastures.

The screenshot shows the 'Graphical Function' dialog box. It features a graph with 'Effect of available water for irrigation' on the y-axis (ranging from 0.000 to 1.500) and 'Vegetation.Radius\_available\_water\_for\_irrigation' on the x-axis (ranging from 0.000 to 2.000). The graph shows a concave-down curve. To the right of the graph is a data table with two columns: 'Vegetation.Radius available water for...' and 'Effect of available water for irrigation'. Below the graph, there are input fields for the x-axis label, 'Data Points' (set to 11), and 'Edit Output'. At the bottom, there are buttons for 'Delete Graph', 'Cancel', and 'OK'.

Vegetation.Radius available water for...	Effect of available water for irrigation
0.000	0.000
0.200	0.270
0.400	0.510
0.600	0.713
0.800	0.870
1.000	1.000
1.200	1.103
1.400	1.193
1.600	1.253
1.800	1.283
2.000	1.298

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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

```

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```

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

The screenshot shows the SAHEL simulation interface. On the left, there is a 'Policies' panel with 11 items, each with a status indicator (orange or green circle) and a toggle button. The items are categorized into 'Implemented to the population', 'Implemented to the herds', 'Implemented to vegetation', and 'Implemented to water'. The 'Simulation' tab is active, showing a control panel with buttons for REST-HALT, RUN, PAUSE, STOP, RESUME, and RUN/RES. Below this is a 'Directions' section with a line graph titled 'Desert of the Sahel'. The graph plots five variables over 25 years: 1) Vegetation (blue), 2) Pasture (orange), 3) Animals (purple), 4) Population (red), and 5) Water (green). The Y-axis ranges from 0 to 150. The graph shows a complex dynamic system with multiple peaks and troughs. A 'Conclusion' section is visible at the bottom.