Sahel Learning Lab.

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Good Governance in a Complex World

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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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Modeling a sustainable lifestyle for the Sahel.

Catastrophe in the Sahel, originated from a well-intentioned intervention.

The Sahel is relatively a narrow strip of land that runs across the Northern Africa, just below the great desert of Sahara. The Sahel has been the home of nomadic people for centuries. It has never been easy to live in the vicinity of the precarious balance of the Sahel, but the nomadic people has survived surprisingly well. They lived with their herds of small number of animals, which kept them moving from one place to another looking for pastures. The nomads knew when an oasis was ready to enter and exit. They also knew that excesive shepherding will increase the regeneration time the pasture takes and that if they didn't respect it their animals could die of starvation. All these skills have been dominated over the years, maybe through trial and error, giving place to a deep knowledge of this environment where nomads lived.

Illustration 1: Map of the Sahel at the Northern Africa.

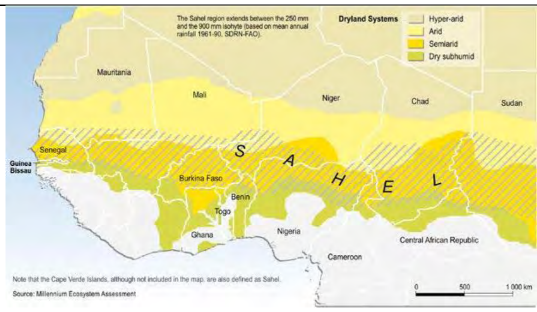


Illustration 2: Map of the Sahel at the Northern Africa. Some scientists include Eritrea as part of the Sahel.

In many ways, the nomads thrived through caring and respecting the environment. Due to the limited amount of available grass, the herds have never been very large, and since people lived from their herds, through the direct consumption of their milk products to obtain cash and buy other necessities of life, the human population has remained fairly small.

The infant mortality was high and the average expectative of life was low in the conditions of this hostil desert. There are also evidences of the practice of primitive forms of family planning, through the use of certain herbs and the nomadic lifestyle to create low-fertility rates.

Illustration 3: Near the village of Ndiagene Wolof in Senegal at the Sahel.

Illustration 4: Livestock concentrated around a waterhole, near to Bamako, Mali, Africa.

The area receives a few inches of rain each year. Some of the runoffs were stored in surface ponds that provide water for the maintenance of the herds and human consumption. The rest of the water runoff seep into the ground or is used directly for the irrigation of the oasis. Some of the groundwater was extracted using water pumps of shallow wells, which usually dried after some use. In long-term, the water consumption and its runoff must operate in a balanced way.

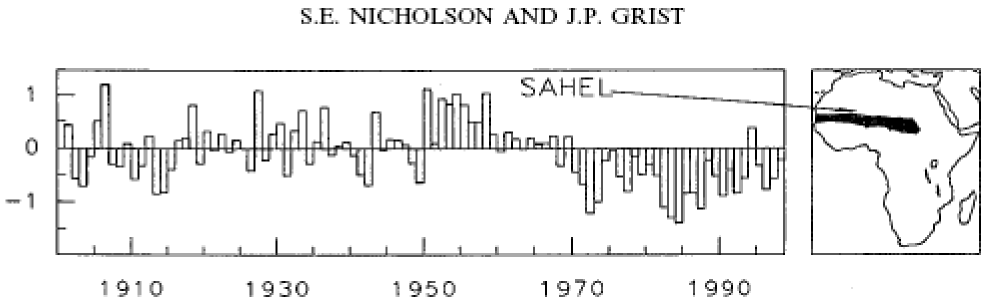


Illustration 5: Variations of rainfall in the African Sahel from 1901 to 1997, expressed as a standard deviation of the regional average (Calculated as the long-term average, divided by the standard deviation) (from Nicholson et al., 2000). Notice the low average of rainfall from 1960 to the 1990 decade. (1980 was the driest decade of the 20th century).

A few decades ago, the people from around the world, working for other organizations as the United Nations (UN), decided to act for improving the quality of nomadic life from the Sahel. Three important things were made:

1. In first place the modern medicine was introduced. Nomads were vaccinated against smallpox and measles. Also malaria and sleeping sickness were put under control. These measures increased the life expectancy of people considerably.
2. The diseases of animals were also controled and genetic improvements were introduced in the herds to increase the milk production, its reproductive rate and meat production.
3. In third place, deep wells were dug to carry the pumped water through large pumps for filling the storage tanks from the surface. It increased the capacity of generating more vegetation and the water availability to increase the maintenance of larger livestock herds, achieving a higher productivity that influenced in the change of the nomads' lifestyle. Many people abandoned the nomadic life and settled with their herds of animals in the settlements built around the groundwater-fed areas.

Unfortunately, the delicate balance of the desert couldn't support this new lifestile. After sometime the deep wells began to dry and the vegetation started to disappear. It starved to death the herds, removing from people the only way to survive. This area is facing misery and continuous hunger. The United Nations (UN) and other organizations keep helping, but hunger stay the same. It seems no hope of improving the pathetic conditions for people from the Sahel.

Human Dimensions of Sahel Land Degradation

The drying of the Sahel in the late 20th century caused widespread famine that attracted world-wide attention, including the United Nations Conference on Desertification (UNCOD) in Nairobi, Kenya in 1977, the 1993 Convention to Combat Desertification, the 2006 International Year of the Desert and Desertification, and the Millennium Ecosystem Assessment.

The studies show that climate change strongly influences the Sahel in recent decades, but it is only part of the story:

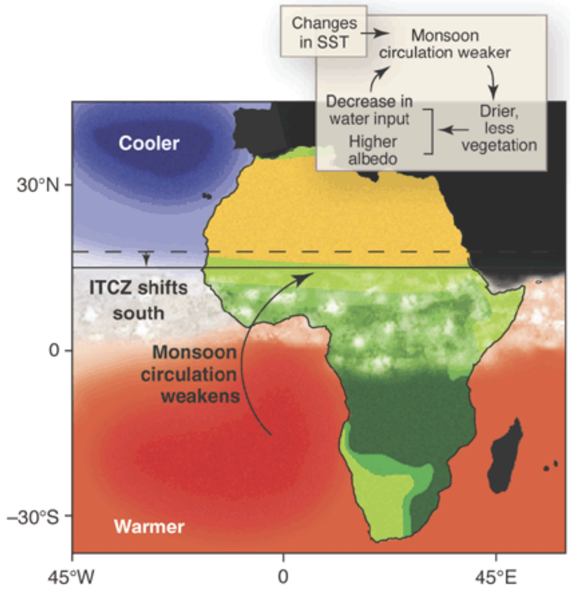


Illustration 6: Changes in Sahel's precipitation are forced by the temperature changes of the surface of the sea in the Gulf of Guinea. The answer has been amplified by the feedback cycles of land-environment from the Sahel, shown in Illustration 4.

Rainfall variability is a major driver of vulnerability in the Sahel. However, blaming the 'environmental crisis' on low and irregular annual rainfall alone would amount to a sheer oversimplification and misunderstanding of the Sahelian dynamics. Climate is nothing but one element in a complex combination of processes that has made agriculture and livestock farming highly unproductive. Over the last half century, the combined effects of population growth, land degradation (deforestation, continuous cropping and overgrazing), reduced and erratic rainfall, lack of coherent environmental policies and misplaced development priorities, have contributed to transform a large proportion of the Sahel into barren land, resulting in the deterioration of the soil and water resources.

From United Nations Environmental Program, World Agroforestry Center. Climate Change and Variability in the Sahel Region: Impacts and Adaptation Strategies in the Agricultural Sector.

The human influences include:

1. Population increase. Population is doubling every 20 years. The growth rate of population (3% per year) exceeds the growth rate of food production (2% per year). The total population is around 260,000,000 people.
2. Poverty. Per capita income varies from $500/year in Burkina Faso to $1,000/year in Mali to $2,000/year in Nigeria. In contrast, the per capita income in France, German, and the UK is about $35,000/year. All are estimates for 2007. The area includes three of the four poorest countries on earth.
3. Over grazing, poor farming methods, and use of trees and vegetation for firewood. Overgrazing and poor agricultural practices lead to soil erosion, further degrading the land.

The traditional Parkland system (integrated crop-tree-livestock systems), which is the predominant land use system and the main provider of food, nutrition, income, and environmental services, is rapidly degrading—woody biodiversity and cover is being lost, and soil fertility is declining from already low levels through exhaustive cropping practices and soil erosion.

From West Africa Drylands Project.

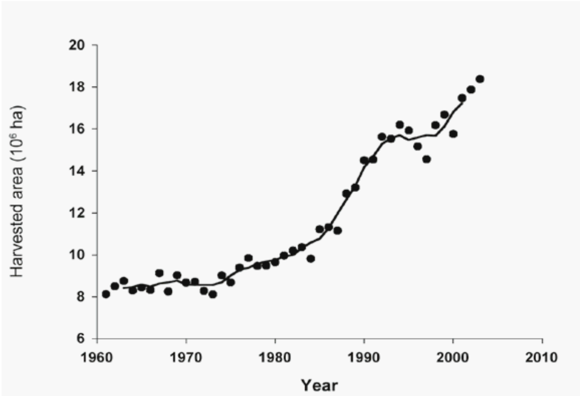


Illustration 7: Area devoted to crops in the Sahel since 1960. The need to grow more crops, both for export and for local use, has led to expansion of agriculture into areas poorly suited for crops, leading to land degradation in dry years.

From United Nations Environmental Program, World Agroforestry Center. Climate Change and Variability in the Sahel Region: Impacts and Adaptation Strategies in the Agricultural Sector.

4. Colonial Influence. The Sahel was divided into countries by European nations. The boarders were set by political processes that mostly ignored the local people and their use of the land. The new countries began to enforce boundaries limiting the ability of nomads to move their herds in response to changing rain, from dry to wet areas. As a result, nomads were forced into villages, and in dry years their herds overgrazed the area around villages and cities.

Unfortunately, this film of well-intentioned interventions in the environment and its interaction with the different cause-effect cycles in various regions of world, continue again and again so often with disastrous results.

I was born and growth up in the Northeastern Mexico in a small city called Melchor Muzquiz in the center of Coahuila State. At present I live in Monterrey, the capital of the neighboring State called Nuevo Leon with a similar weather as Muzquiz, with low annual rainfall, semi-desert with sparse vegetation and a similar panorama as the Sahel, although not that extreme. Life here isn't nomadic, even though the connection of water cycles, the growth of pastures for animal feeding, the use of milk products and the improvement of the human welfare, follow similar patterns as the Sahel. Hence the need of creating a simulation model that help us to generate new policies to develop a long-term sustainable life in harmony with the environment and its underlying cause-effect cycles. In Nuevo Leon is common to see the herds of goats in field. Cabrito is a typical dish with international fame, so it's very important to help improving the financial outcome of its producers and the management of the ranches in harmony with nature.

Expected behavior of subsystems from the Sahel.

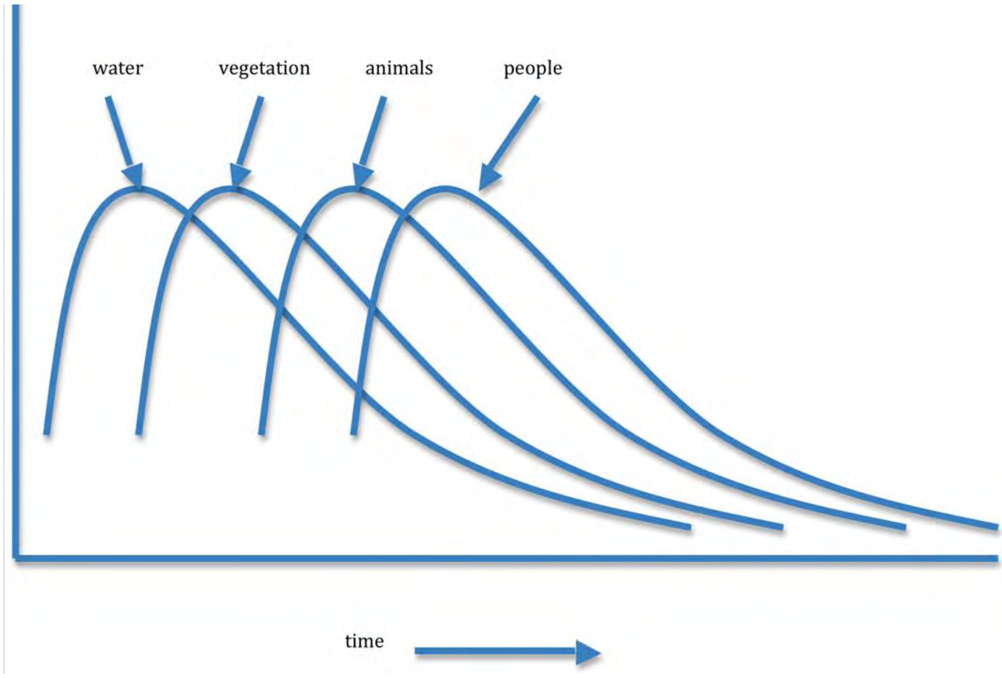


Illustration 8: Expected behavior of subsystems from the Sahel. (Water, vegetation, animals and people.)

Steps for the development of learning jab.

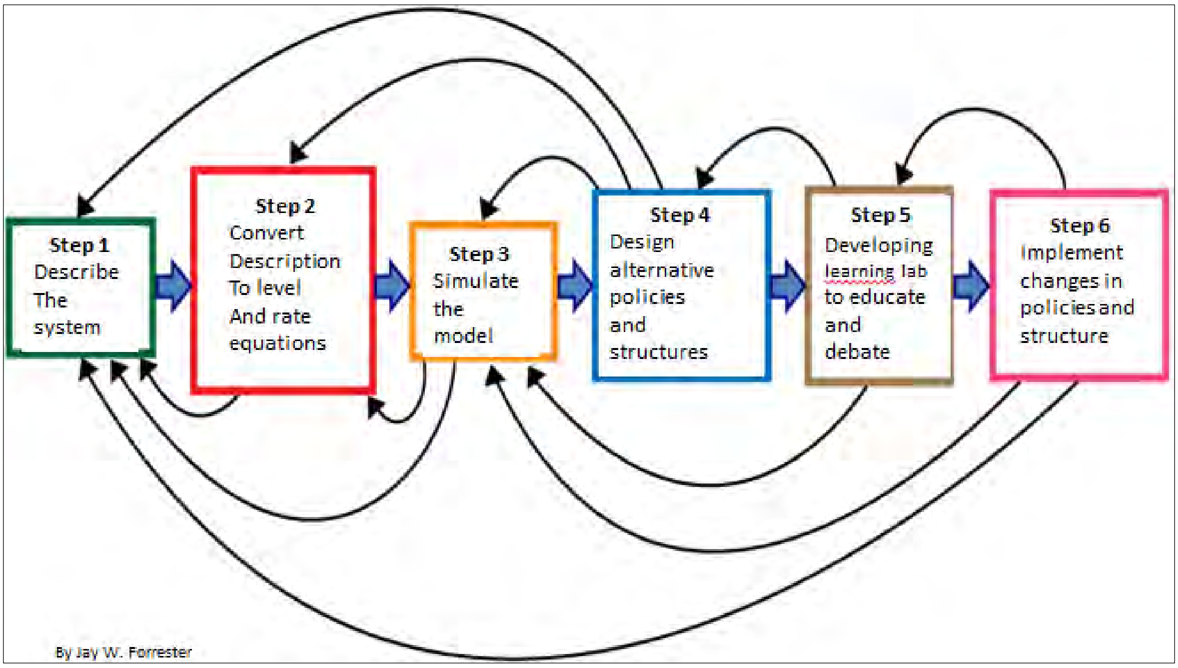
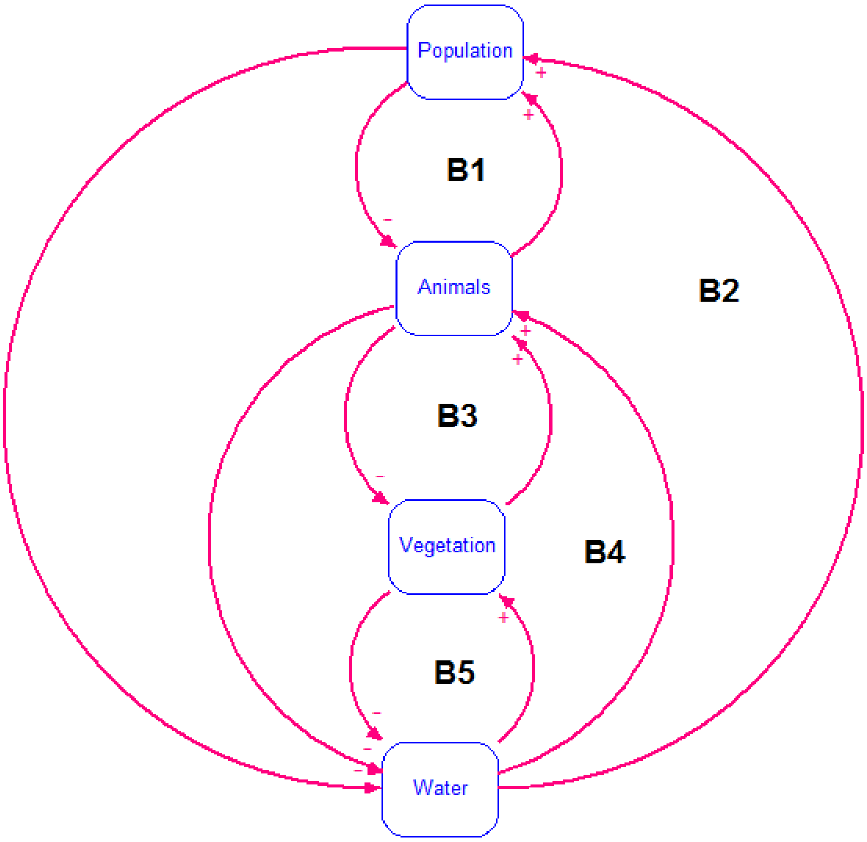


Illustration 9: Steps for the development of learning laboratories and their results.

Sahel – System Modules



Note: You can review the material support to view the module details.

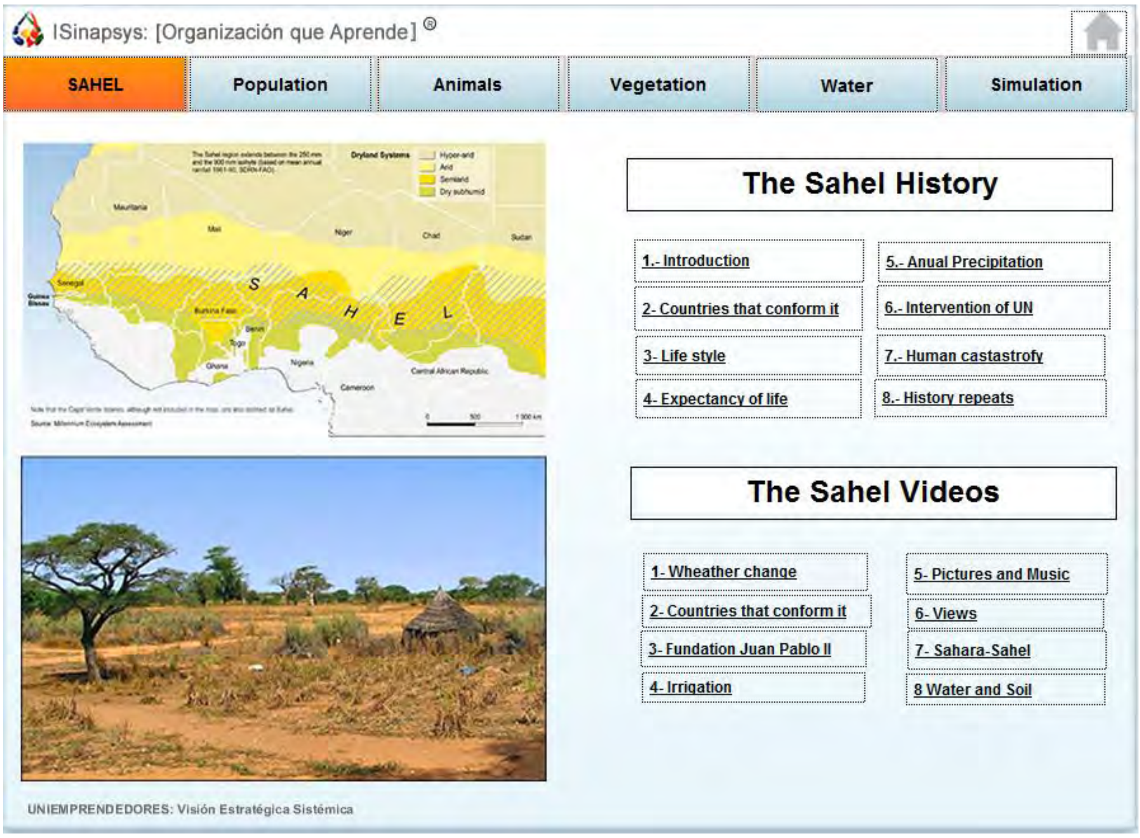
Development model step by step.

Modeling a sustainable lifestyle.

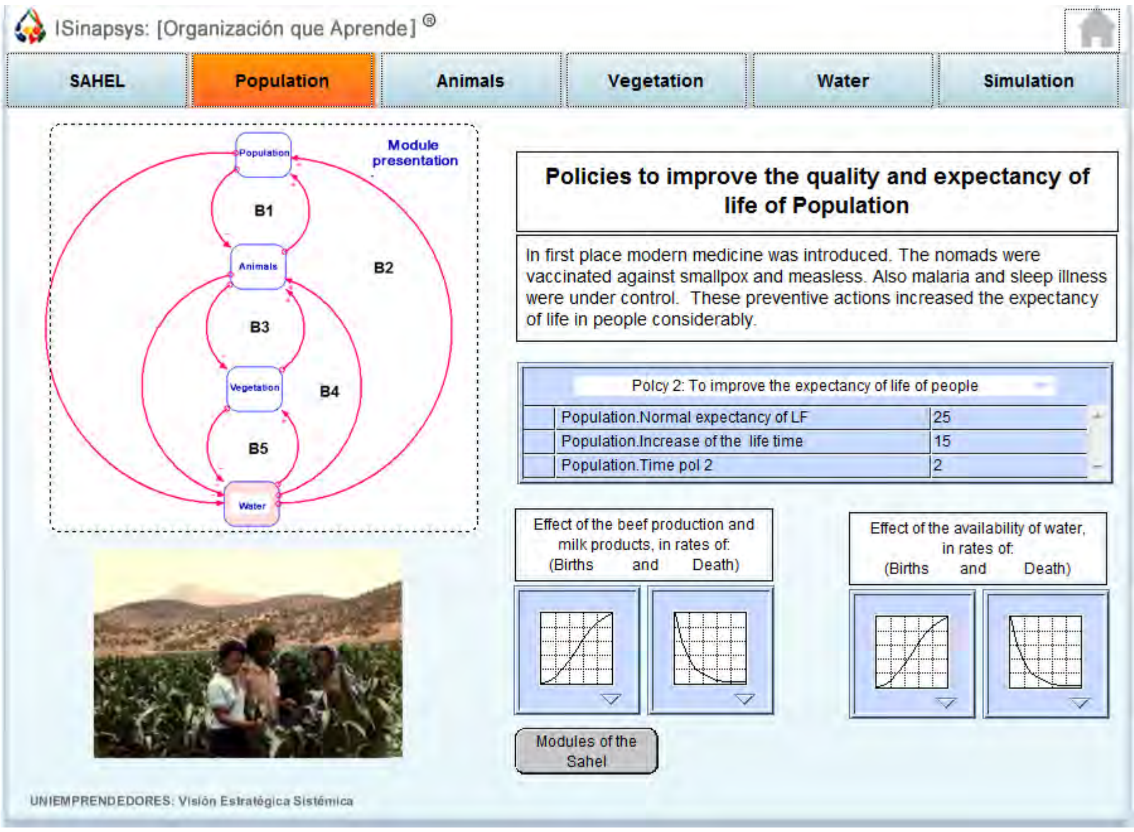
In this occasion, we've developed a complete bussiness game to solve the Sael's Model, where step by step we'll explain the pieces involved:

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.

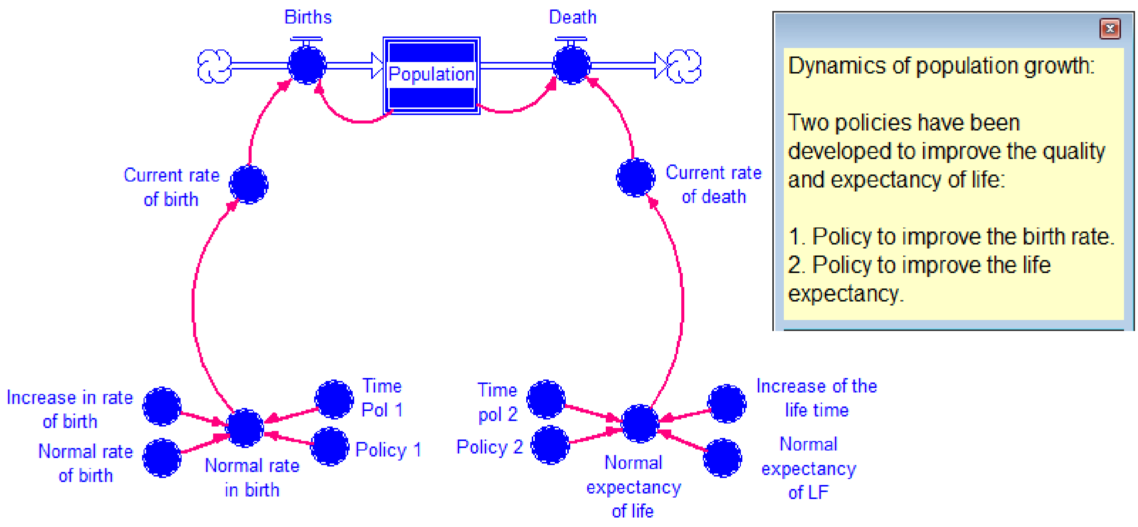
SAHEL – Its written and video history.



The population module.

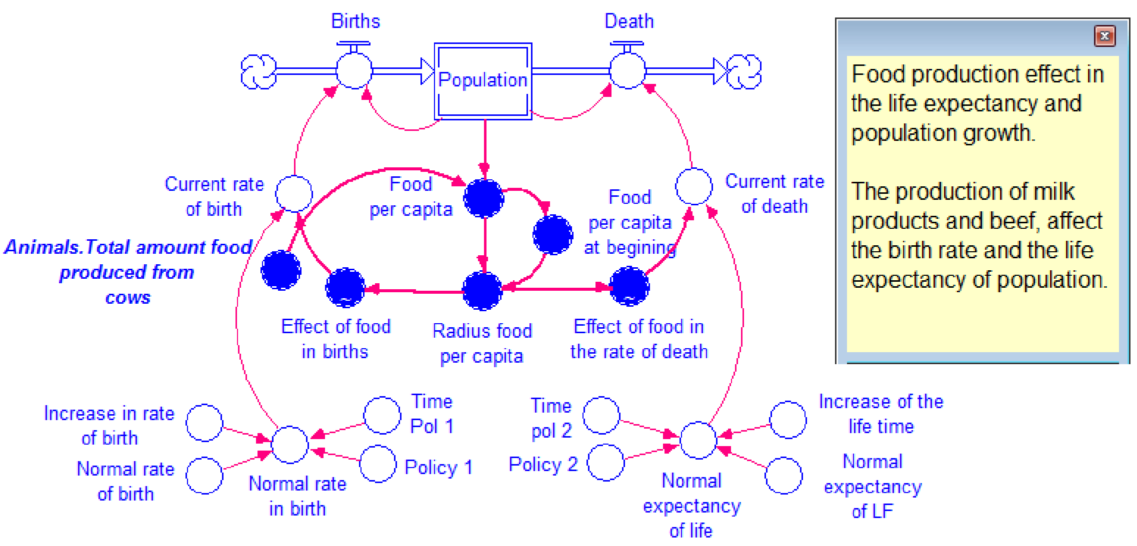


Systemic dynamics of the population growht.

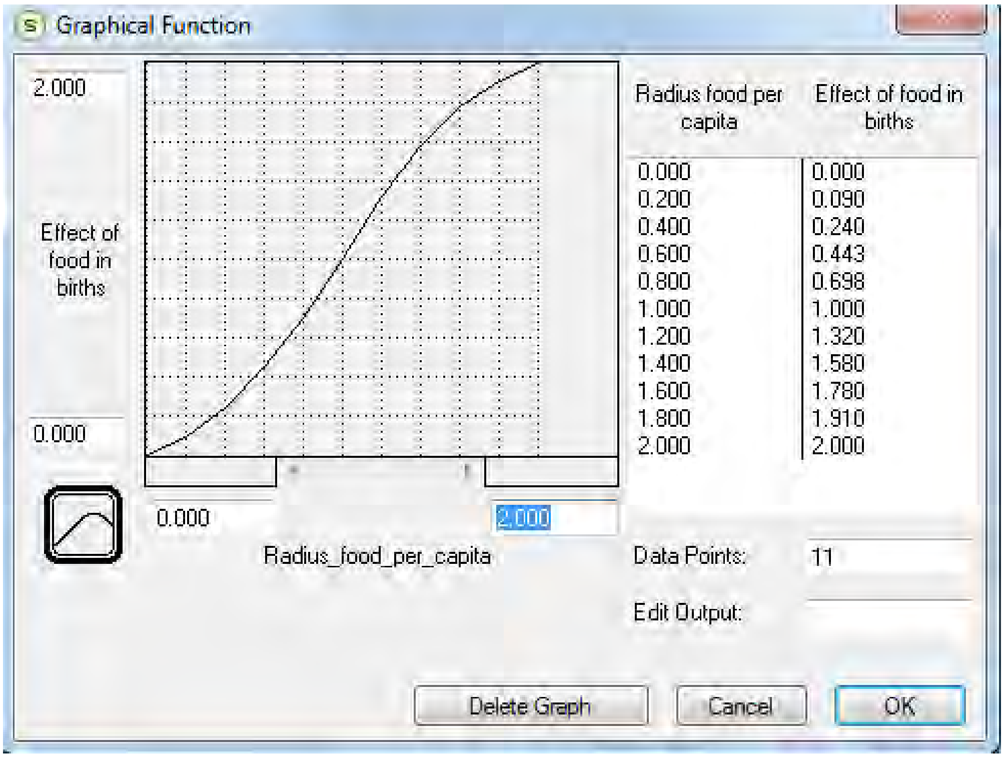


The normal rate of births and deaths, can be modified by the effects of food availability from animal products or from the water.

Effect of food production from animal herds in the quality of life and the population growth.

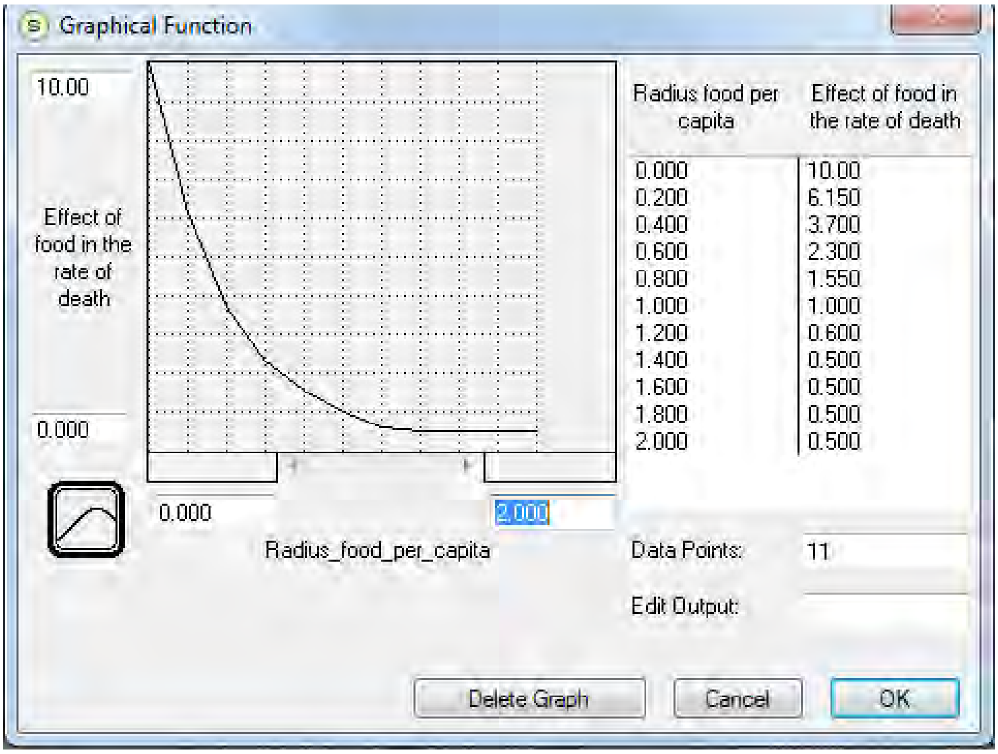


Graph of the effect of the food produced in the newborn.

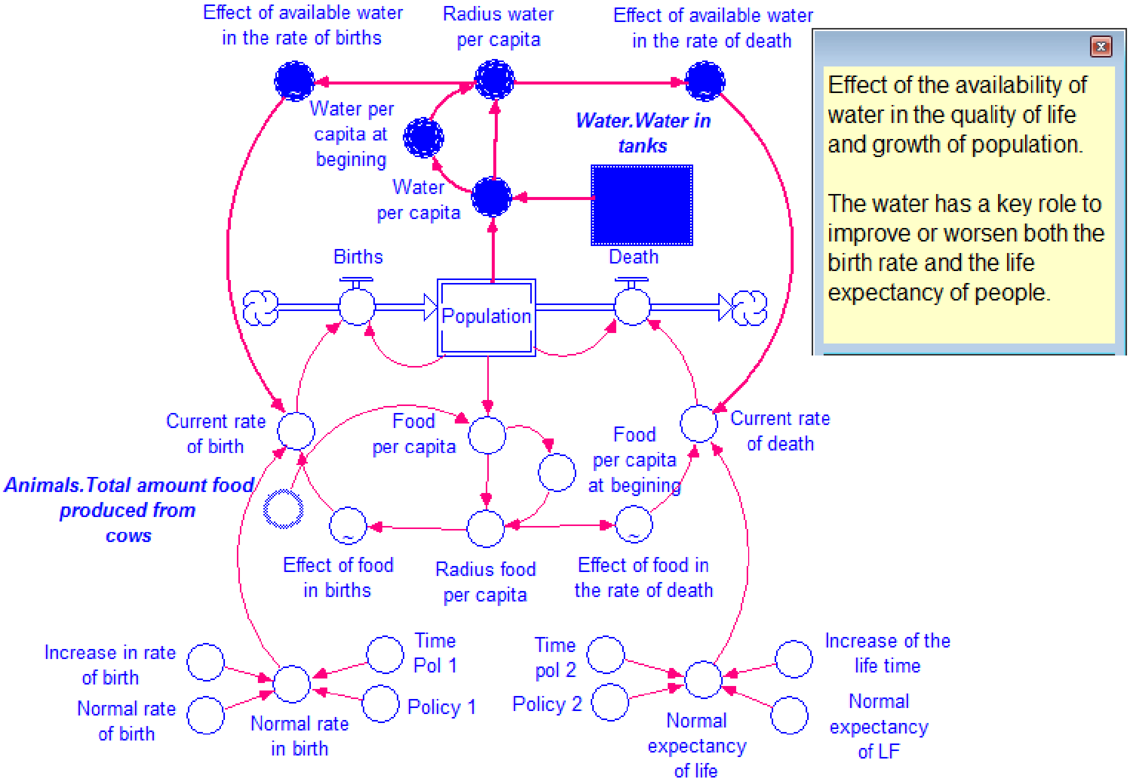


If the radius of food per cápita is greater than 1 the birth rate rises, if is less than 1 decreases.

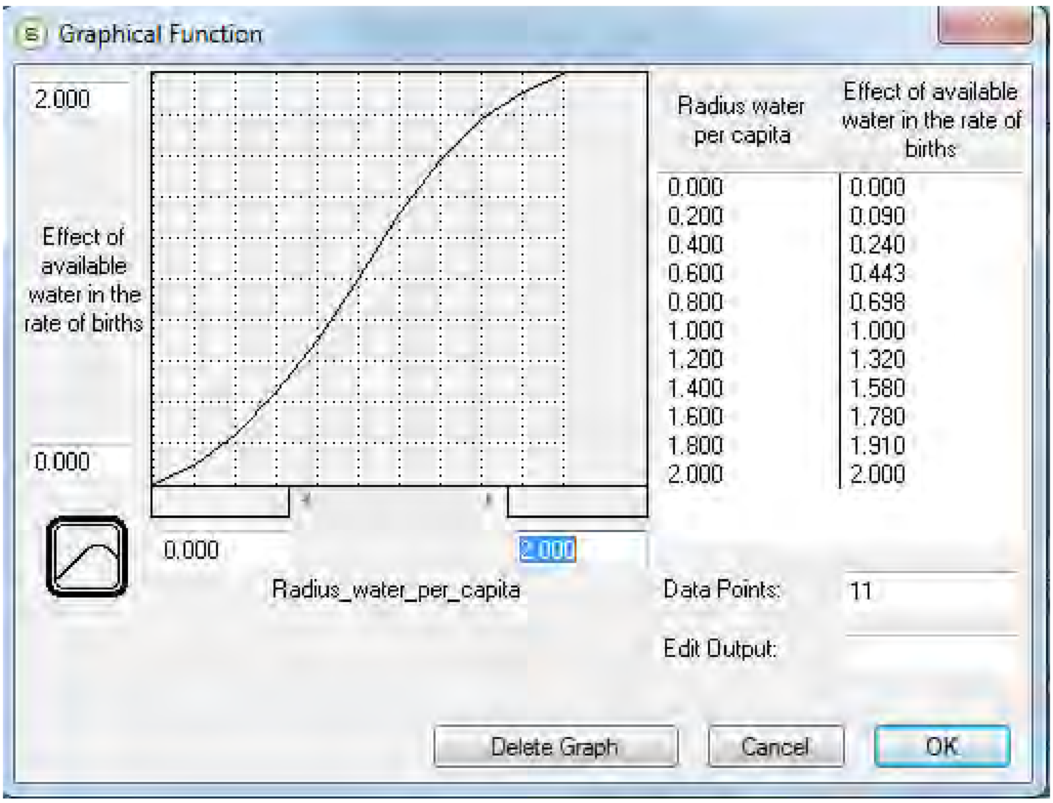
Graph of the food effect produced in the death rate.



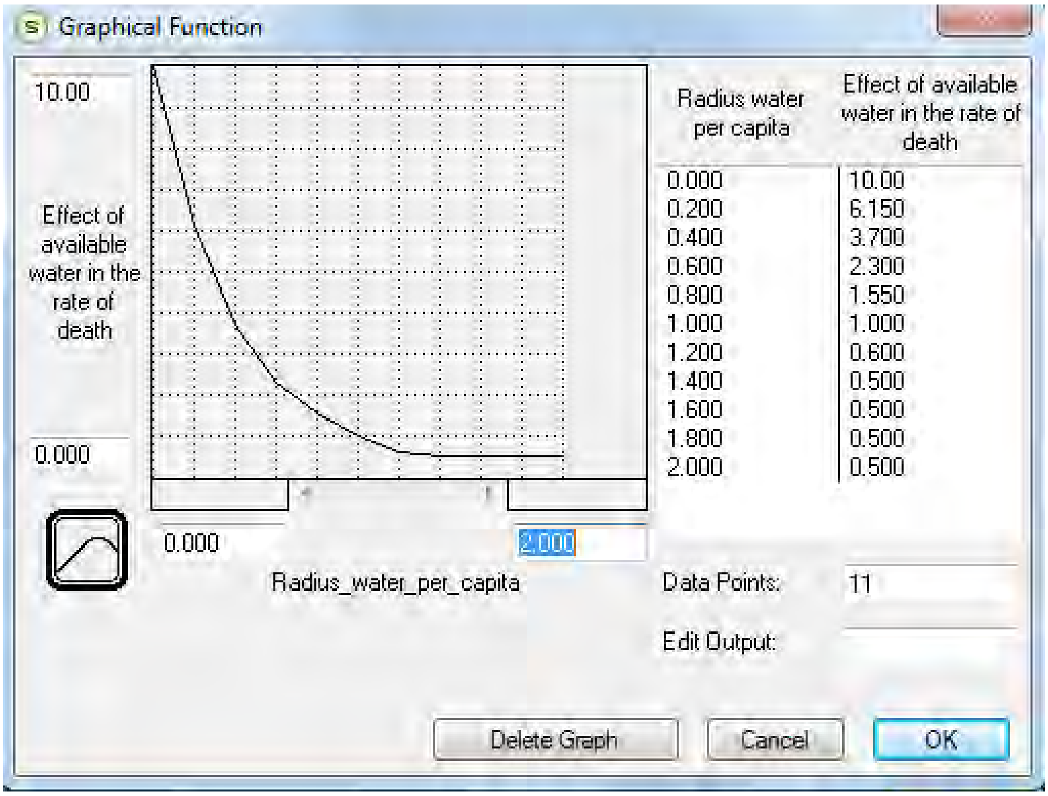
Effect of water availability in the quality of life and the population growth.



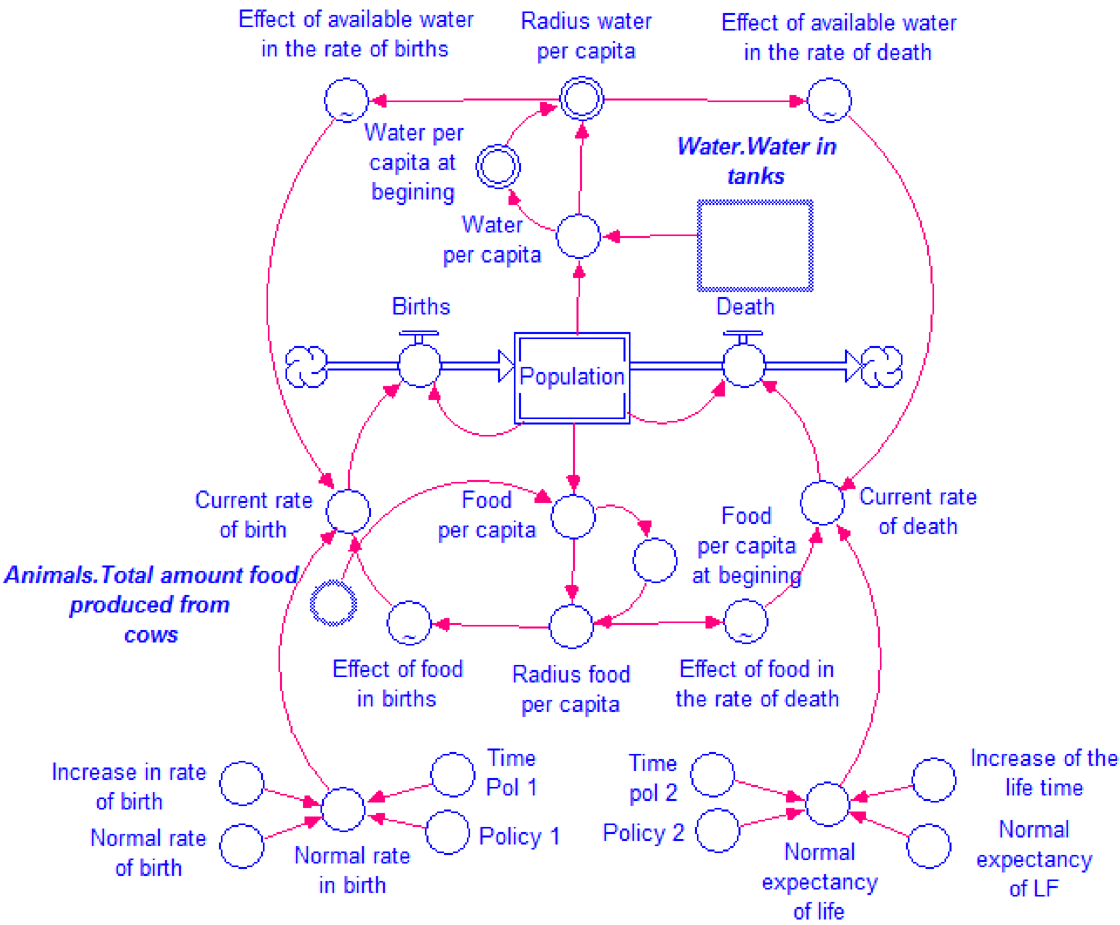
Graph of the effect of available water in the birth rate.



Graph of the effect of available water in the death rate.



Complete model for the population dynamics.



Here, all the elements involved in the population module, are shown:

1. The policy of disease prevention, such as vaccines to improve the birth rates and life expectancy.
2. The effect of food production on the birth and death rates of people.
3. The effect of water availability on the population growth and, their quality and life expectancy.
4. The graphs of the non-linear effects of the availability of food and water in birth rates and population expectancy of life.
5. The relationship cause-effect of the population with the modules of animals (Total amount of food produced by cows) and water availability (water in the ponds).
6. Among the policies implemented to increase the birth rates and decrease the death rates, the data about the expectancy of improvement in mentioned rates with the health campaigns implemented, are recorded. It's clear that this will happen if the availability of food, water and monetary wealth of milk products generated for sale in the market and their own consmption, are also implemented.

Equations of the population model.

Population(t) = Population(t - dt) + (Births - Death) * dt
INIT Population = 100
INFLOWS:
Births = Population*Current_rate_of_birth
OUTFLOWS:
Death = Population*Current_rate__of_death
Current_rate_of_birth =
Normal_rate_in_birth*Effect_of_food_in_births*Effect_of_available_water_in_the_rate_of_births
Current_rate__of_death =
(1.0/Normal_expectancy_of_life)*Effect_of_food_in_the_rate_of_death*Effect_of_available_water_in_the_rate_of_death
Food_per_capita = Animals.Total_amount_food_produced_from_cows/MAX(0.001,Population)
Food_per_capita_at_begining = Init(Food_per_capita)
Increase_in_rate_of_birth = 0.02
Increase_of_the__life_time = 15
Normal_expectancy_of_LF = 25
Normal_expectancy_of_life = if (Policy_2=1) then
Normal_expectancy_of_LF+STEP(Increase_of_the__life_time,Time_pol_2) else
Normal_expectancy_of_LF
Normal_rate_in_birth = if (Policy_1=1) then
Normal_rate_of_birth+NORMAL(1,.2)+STEP(Increase_in_rate_of_birth,Time_Pol_1) else
Normal_rate_of_birth
Normal_rate_of_birth = .04
Policy_1 = 0
Policy_2 = 1
Radius_food_per_capita = Food_per_capita/MAX(0.001,Food_per_capita_at_begining)
Radius_water_per_capita = Water_per_capita/MAX(0.001,Water_per_capita_at_begining)
Time_Pol_1 = 5
Time_pol_2 = 2
Water_per_capita = Water.Water_in_tanks/MAX(0.001,Population)
Water_per_capita_at_begining = Init(Water_per_capita)
Effect_of_available_water_in_the_rate_of_births = GRAPH(Radius_water_per_capita)
(0.00, 0.00), (0.2, 0.09), (0.4, 0.24), (0.6, 0.443), (0.8, 0.698), (1.00, 1.00), (1.20, 1.32), (1.40, 1.58), (1.60, 1.78), (1.80, 1.91), (2.00, 2.00)
Effect_of_available_water_in_the_rate_of_death = GRAPH(Radius_water_per_capita)

(0.00, 10.0), (0.2, 6.15), (0.4, 3.70), (0.6, 2.30), (0.8, 1.55), (1.00, 1.00), (1.20, 0.6), (1.40, 0.5), (1.60, 0.5), (1.80, 0.5), (2.00, 0.5)

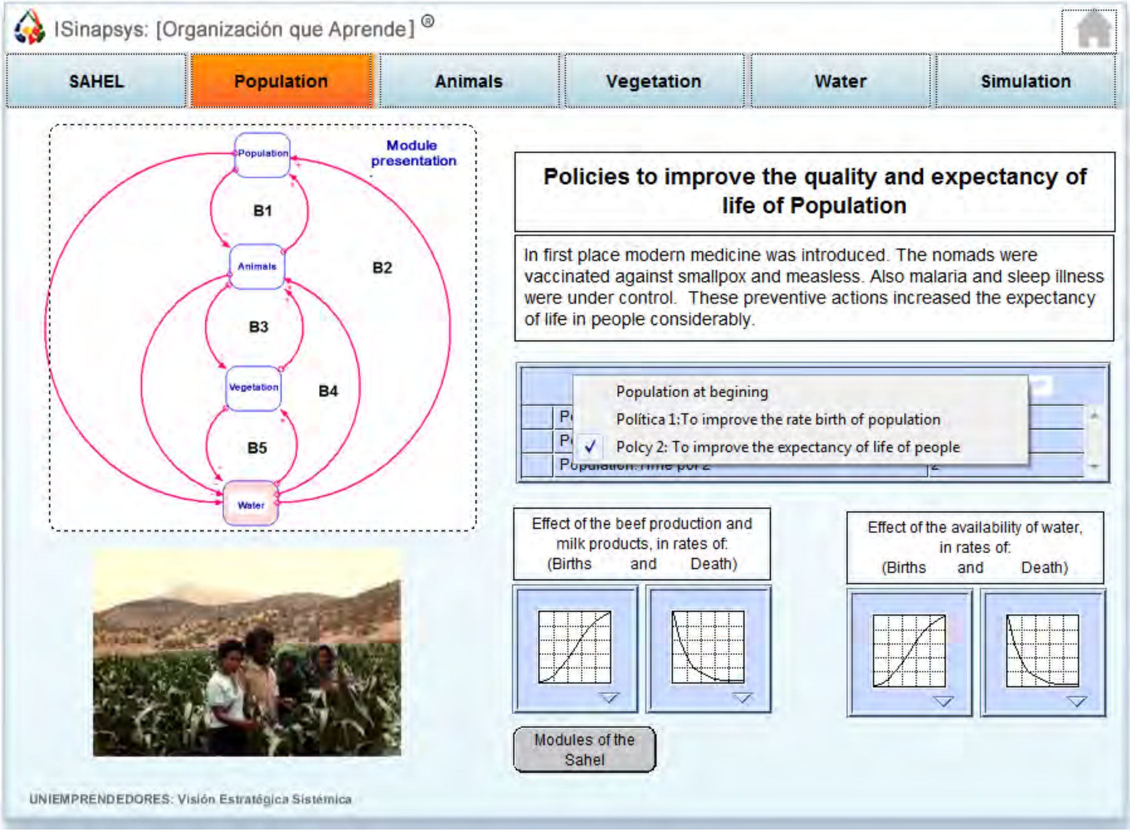
Effect_of_food_in_births = GRAPH(Radius_food_per_capita)

(0.00, 0.00), (0.2, 0.09), (0.4, 0.24), (0.6, 0.443), (0.8, 0.698), (1.00, 1.00), (1.20, 1.32), (1.40, 1.58), (1.60, 1.78), (1.80, 1.91), (2.00, 2.00)

Effect_of_food_in_the_rate_of_death = GRAPH(Radius_food_per_capita)

(0.00, 10.0), (0.2, 6.15), (0.4, 3.70), (0.6, 2.30), (0.8, 1.55), (1.00, 1.00), (1.20, 0.6), (1.40, 0.5), (1.60, 0.5), (1.80, 0.5), (2.00, 0.5)

Other policies and initial data for the population module.



In this population module, we've created two policies aimed to:

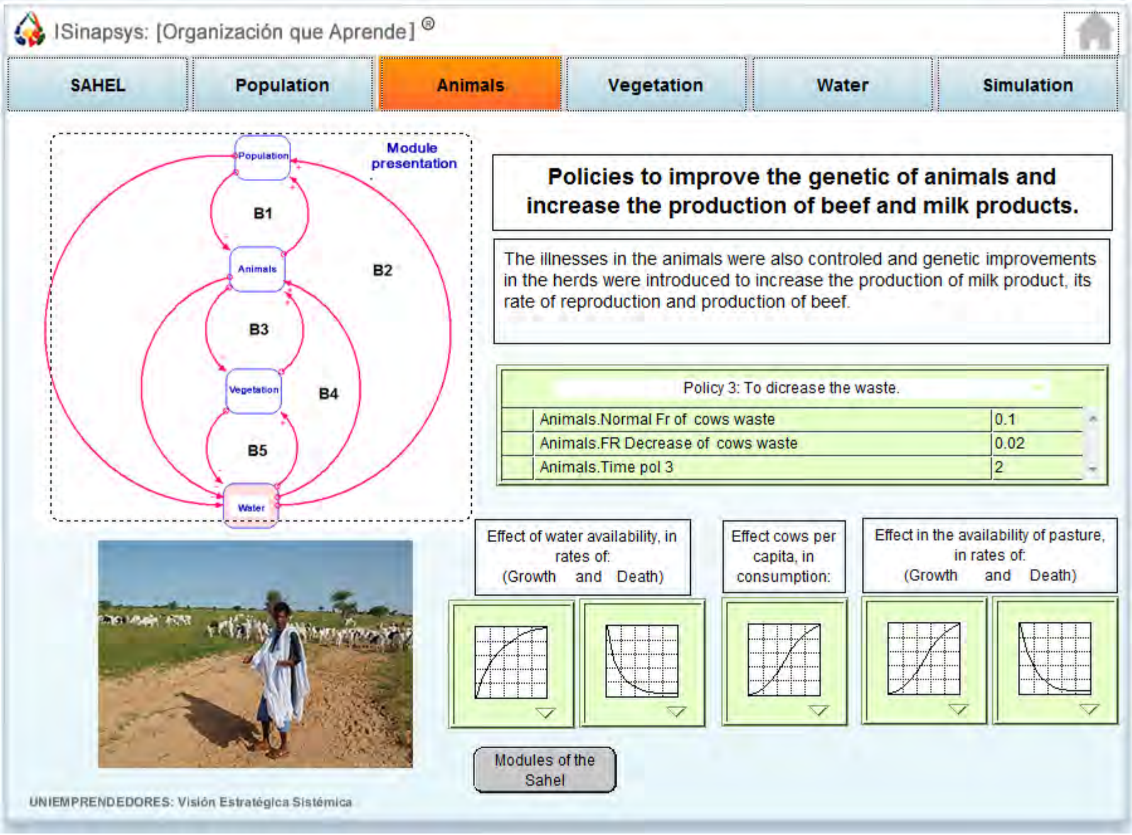
1. Improve the birth rates.
2. Improve the life expectancy of people.

Both have to do with the health of population, implementing vaccination campaigns to prevent diseases such as smallpox and measles wich have a strong impact on children, and others such as malaria, sleeping seeckness, that affect the quality of life and decrease the life expectancy.

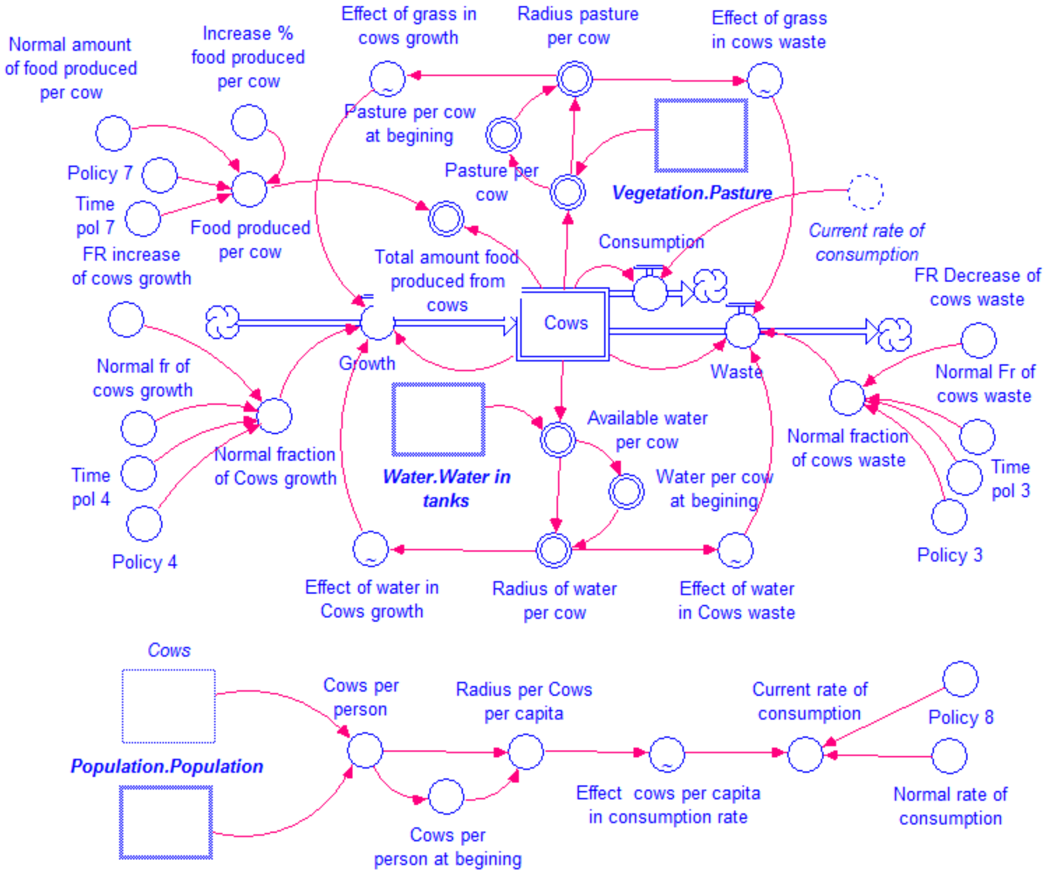
In addition of paying attention to health care issues, there must be attention to other aspects of the ecosystem, such as:

1. The genetic improvement of animals to enhance its meat production, and also in the milk products that function as food and also generate incomes to the population.
2. The overexploitation of aquifers, use, storage and purification of water.
3. The productivity of pastures for the animal consumption.
4. The management of pastures to prevent overgrazing.

Module for the animals.



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.

Note: You can review the material support to view the module details.

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_gro
wth)
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)
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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.

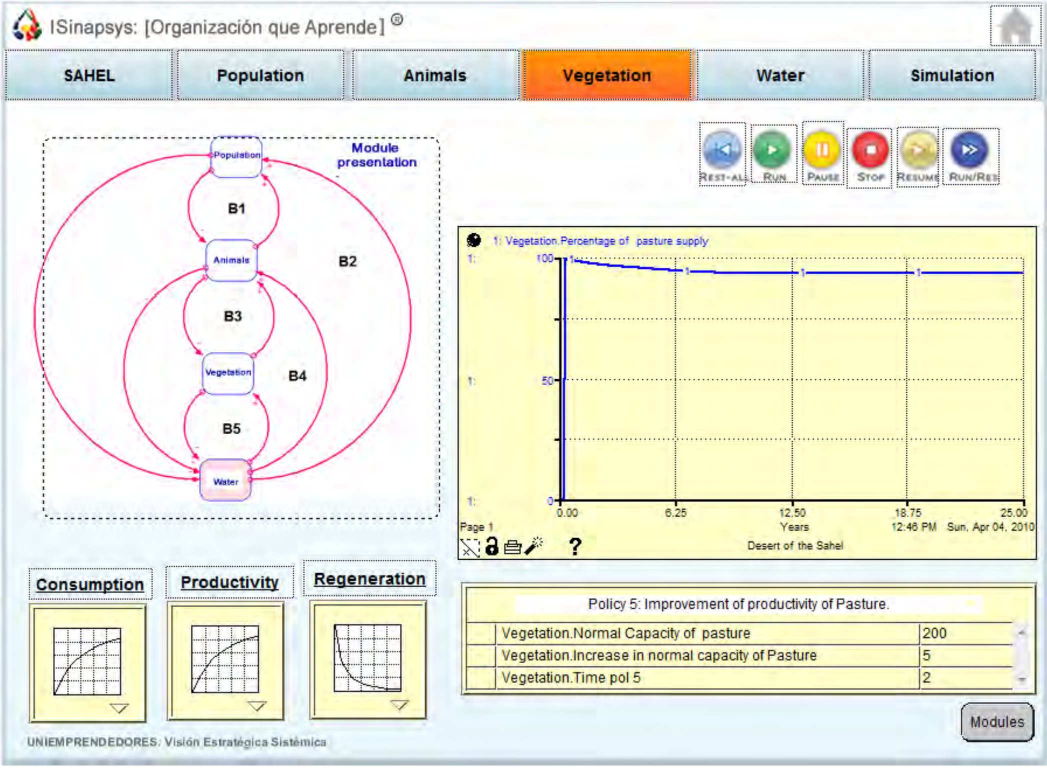
All of them are involved in the genetic improvement of the animals to increase the productivity of their products, improve their reproductive capacity and reduce the natural waste.

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:

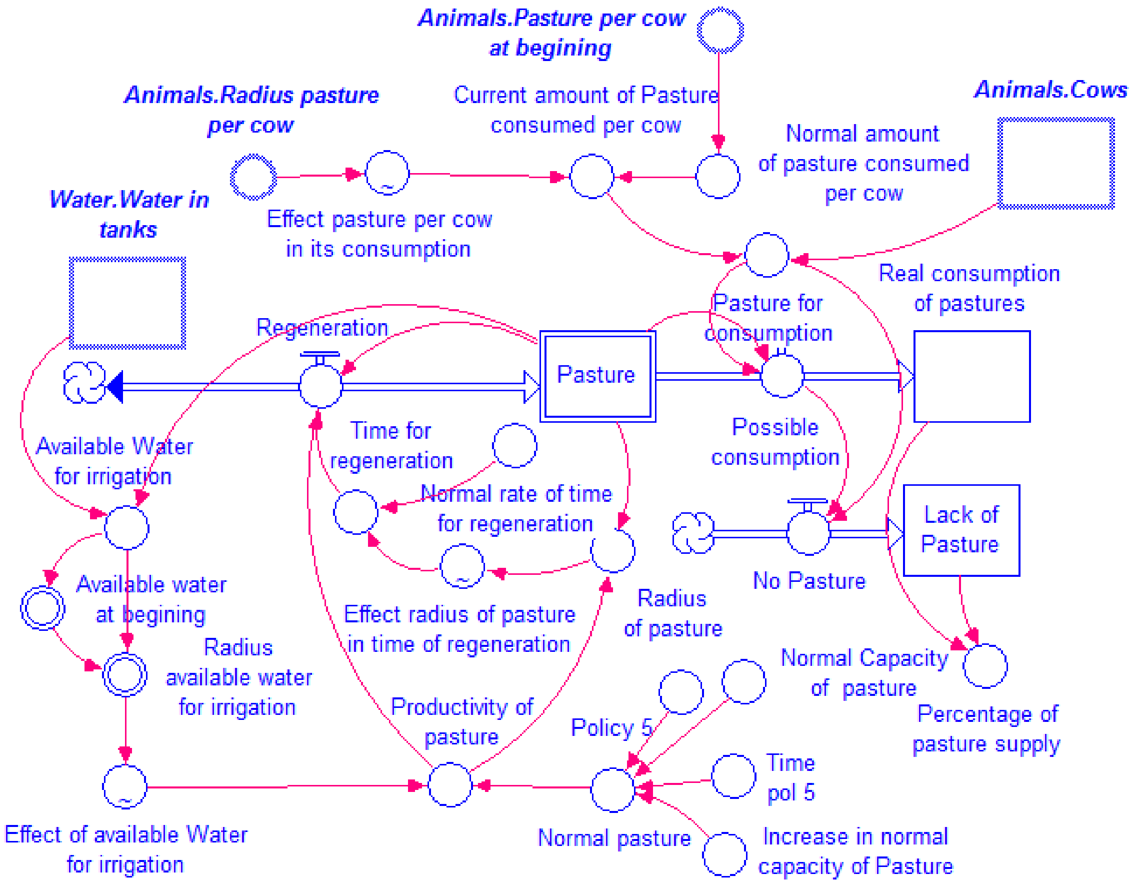
1. The water availability in the surface ponds.
2. The quality of produced grass.

Module for vegetation.



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

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.

Note: You can review the material support to view the module details.

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)

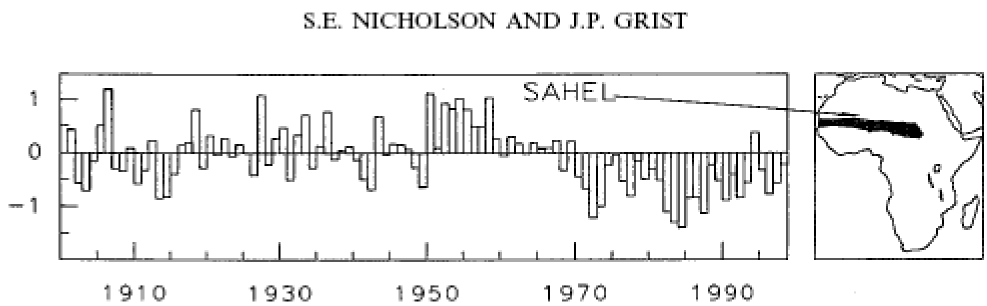
Policies and initial data for the vegetation module.

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

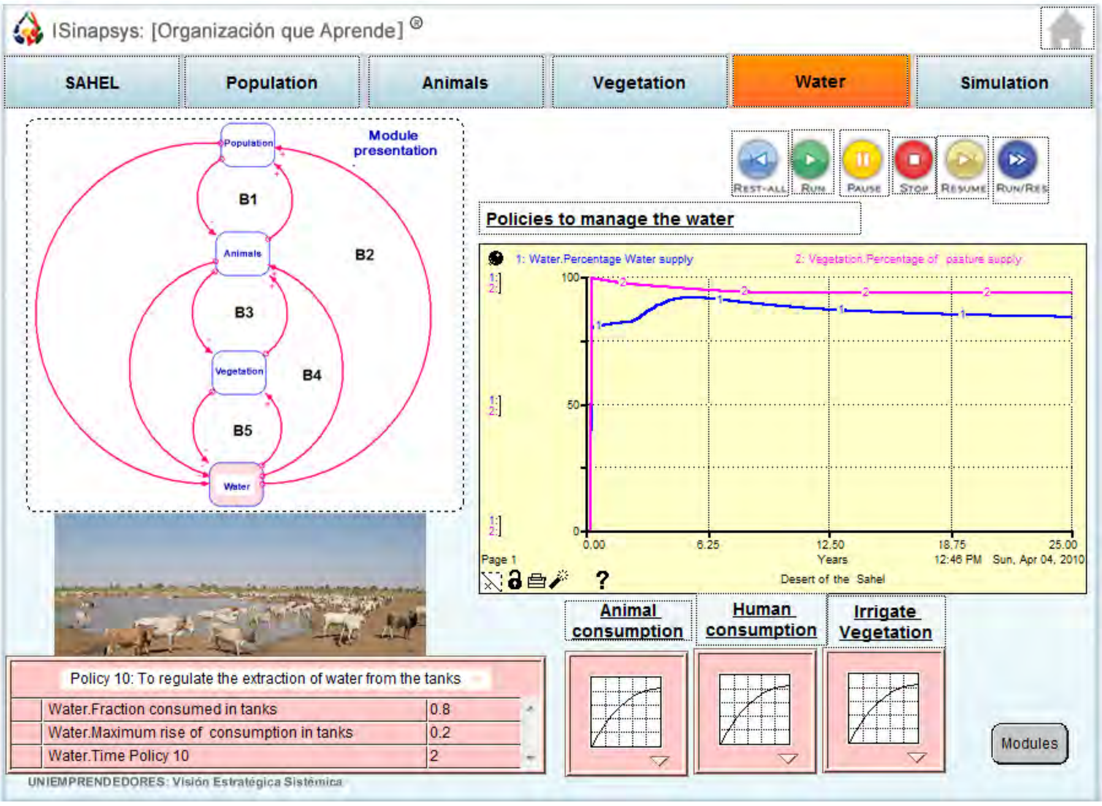
1. The improvement of pasture productivity.

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.

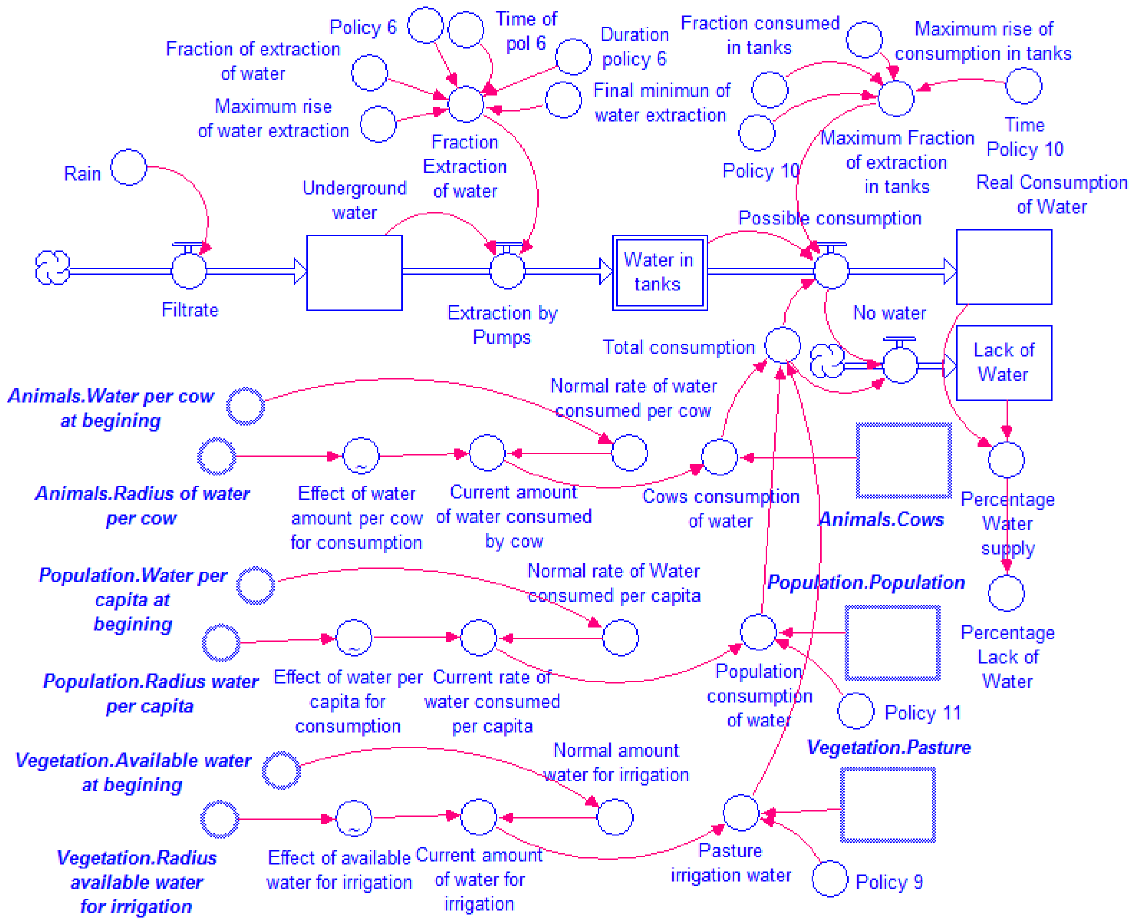
Although generally the vegetation is only watered with rainwater, a policy in the water module has been implemented. This policy establishes that if there is enough water, it can be used directly from the ponds of the surface to water in times when it doesn't rain. The result of the simulation shows 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.



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.

Note: You can review the material support to view the module details.

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

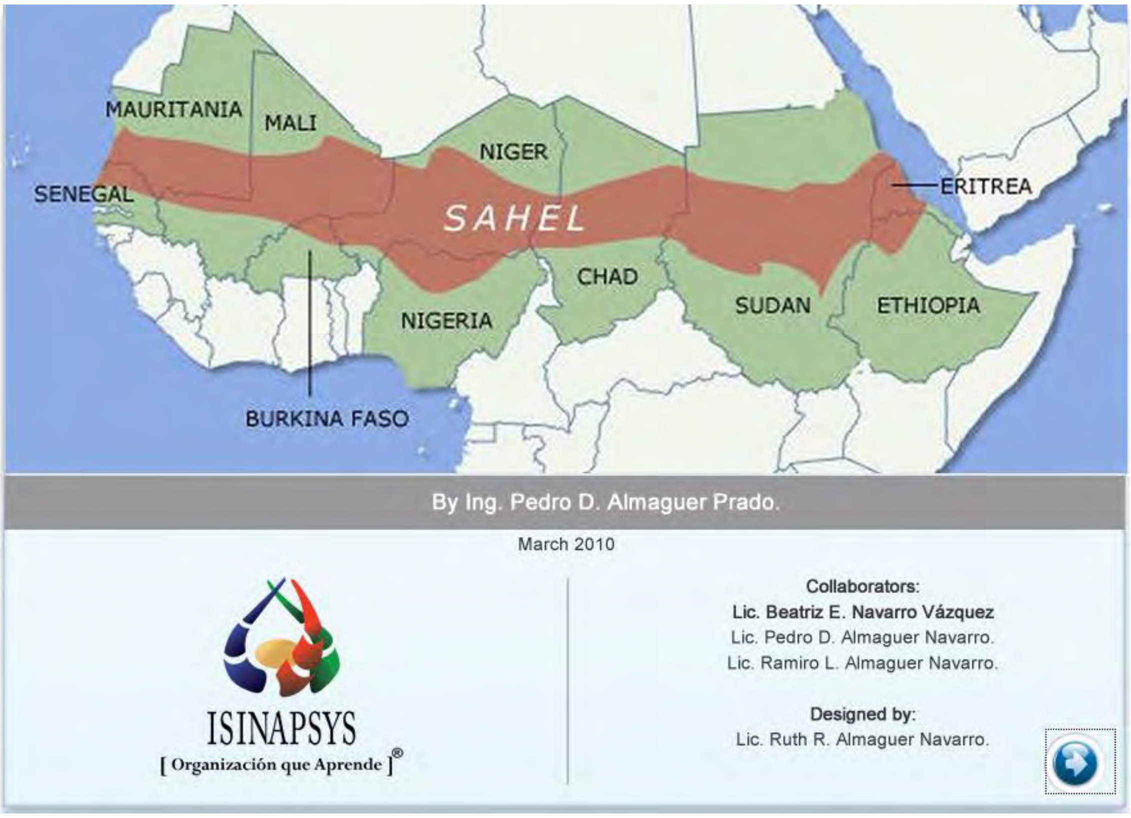
Total_consumption = Pasture_irrigation_water+Population_consumption_of_water+Cows_consumption_of_water

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)

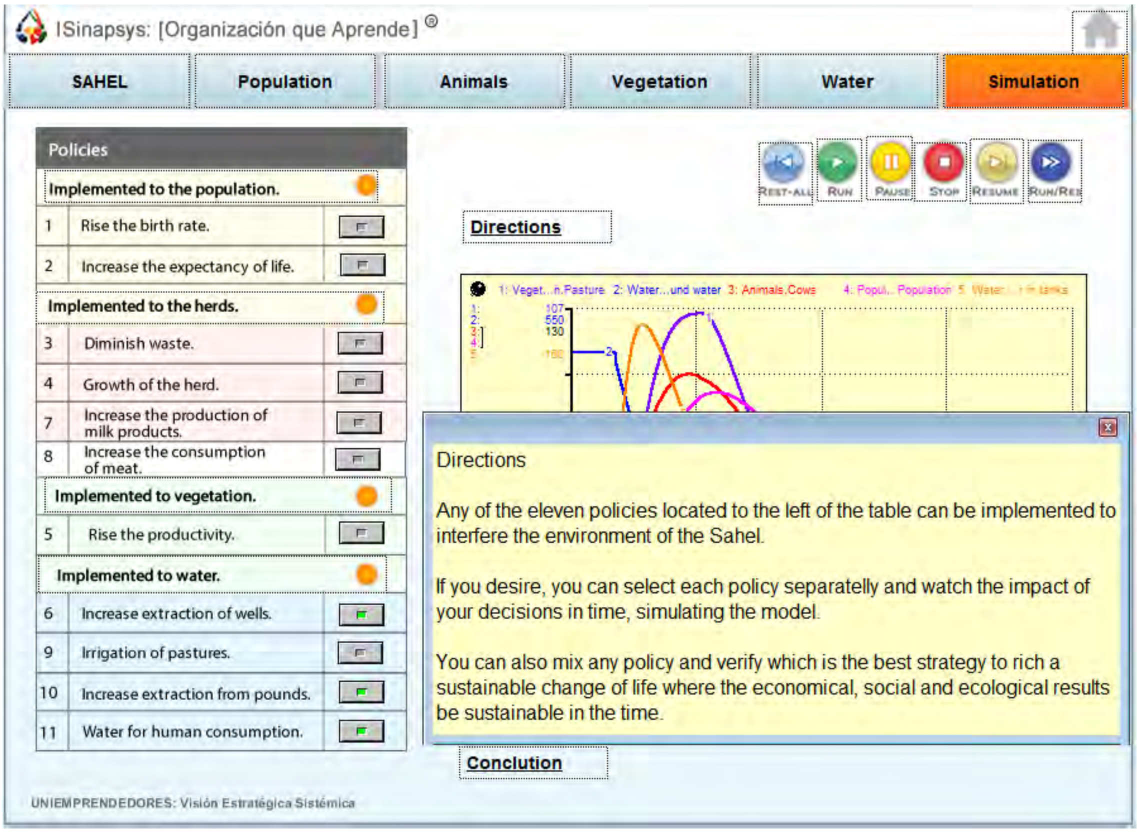
Effect_of_water_per_capita_for_consumption = GRAPH(Population.Radius_water_per_capita)
(0.00, 0.00), (0.2, 0.27), (0.4, 0.51), (0.6, 0.713), (0.8, 0.87), (1.00, 1.00), (1.20, 1.10), (1.40, 1.19), (1.60, 1.25), (1.80, 1.28), (2.00, 1.30)

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)

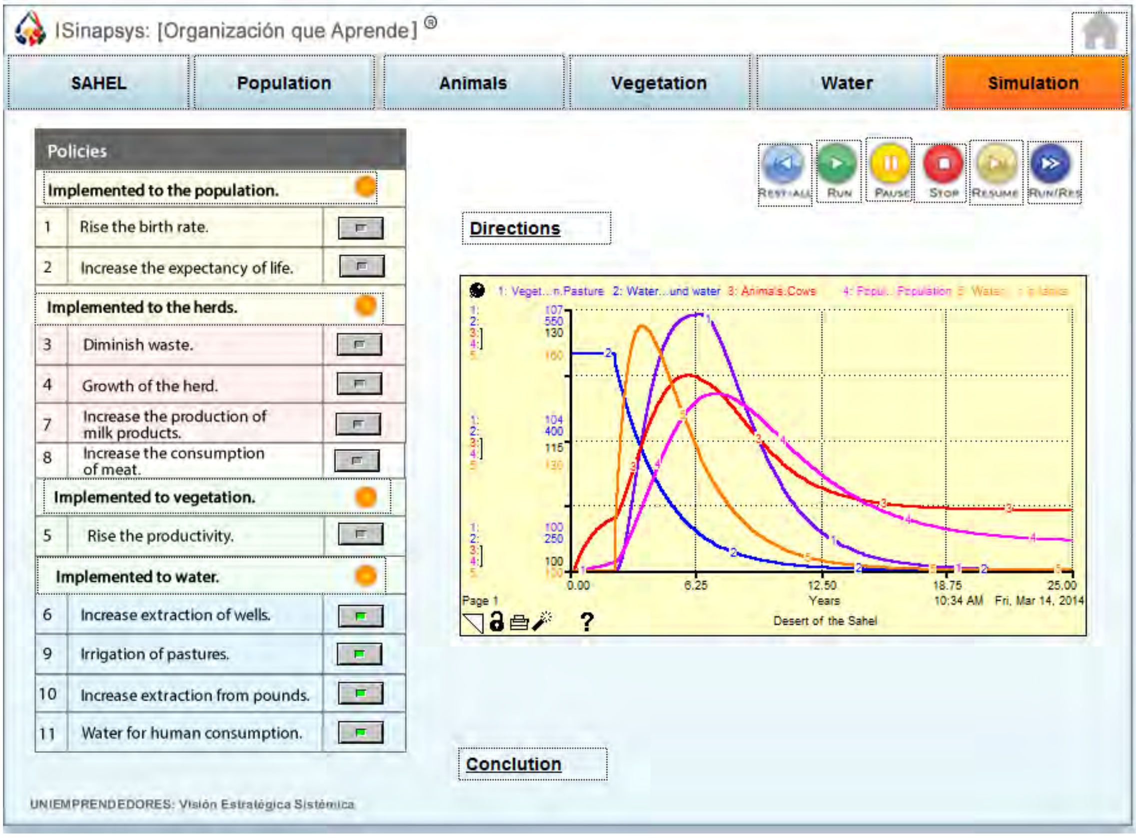
Sahel learning lab



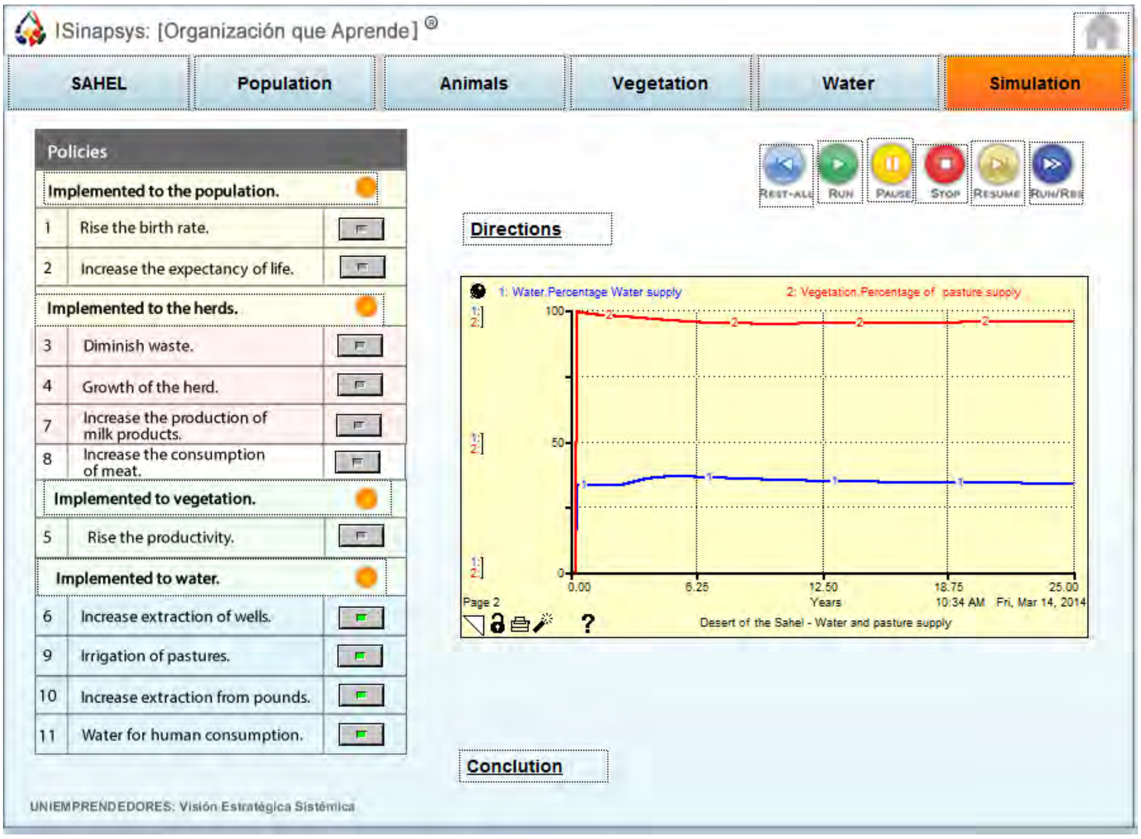
Simulation – Directions



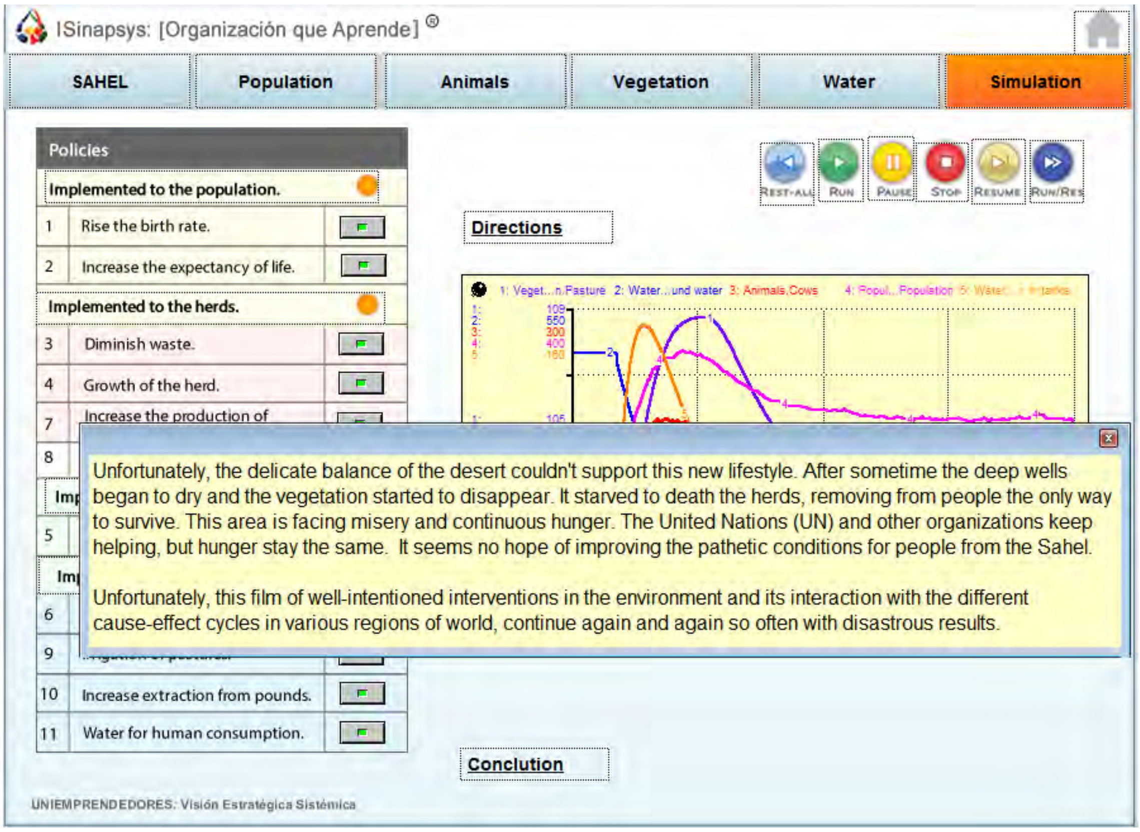
Policies 6, 9 ,10 and 11, pumping and use of animals, plants and people consumption



Effect of the policy of pumping in water supply



Comments



Final comments

With the results of the simulation, perhaps we can highlight that in the chronic water shortage, 50 years of low rainfall, virtually, any strategy tray to deploy, will fail if first is not achieved how to make an efficient water use and consumption.

To take a little care of water, first will have to innovate in awareness campaigns about saving the vital liquid in the town, to find ways to prevent the evaporation from the ponds, to look for the storage as much as possible of the rainfalls in tanks. To find better ways to irrigate the plants through drip, to care the overgrazing to avoid the animals finish vegetation before it can regenerate. To seeck breeding herds and maximize the quality of its products, to improve the pasture productivity, and then, all the applied to human beings to improve their quality and life expectancy.

Conclusion

How stunning case of study, how much complexity, what a fragil ecological balance of the Sahel and many other desertic zones of the wolrd. Any intervention or strategy applied to the development of some of its variables, makes a chain reaction to the others and as we could see, for now, nothing of the applied is sustainable in long-term. It's necessary to continue innovating.

It's important to emphazise the lack of water and drought so prolongued in the recent 50 years (1960 to 2010), it doesn't rain and it paralyzes mostly all the changes in the ecosystem. It's necessary to invent new exploitation methods to use this vital resource, and specially the water storage of rainfall since the moment it falls to keep it in the cisterns built by men. Above all, the technology needed for the drip to avoid the water evaporation and save the vital liquid in the irrigation of pasture and plants.

We must mention that there are some interventions of the UN or other international agencies to assist various regions of the wolrd with very good intentions, they provide proyects with lots of money and human efforts, but a few years later, everything continuos the same. Only the effects are under attack, but the real problem is never addressed. As in the Sahel, in a few years (10 years) the negative cause-effect cycles, cause the necessity of keeping the variables to a new goal if we don't implement solutions that support new positive cause-effect cycles to counteract the negative, hardly the solution will be sustainable in the long-term.

Our mind must be always positive and focused to search the entire ecosystem sustainability. Although we must bear in mind that any solution or strategy we want to implement, will affect in some way the economical, social and ecological. The problems will be always complex because everything goes together and can't be handled separately. For this cause, the modeling, the systemic thinking and simulation, are appropriate to review the impact of our decisions on time, before they are implemented in the real world. It will allow us to study the possible consequences of our decisions in the long-term.

Apendix "A" Simple model of diversification of the economy in the rural areas.

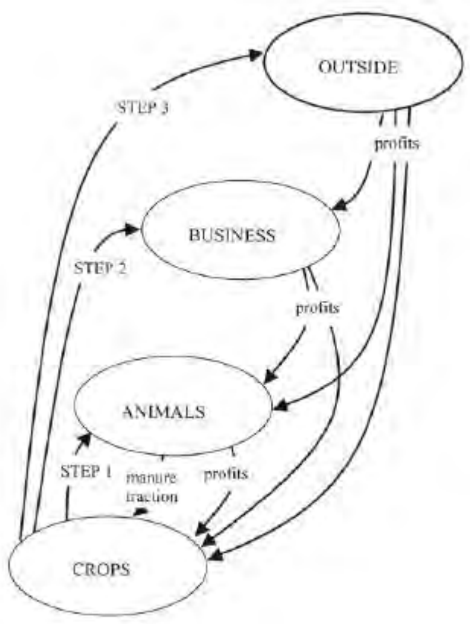


Illustration 10: A simple model of diversification of the economy in the rural households. (adapted from Mortimore & Williams, 1999)

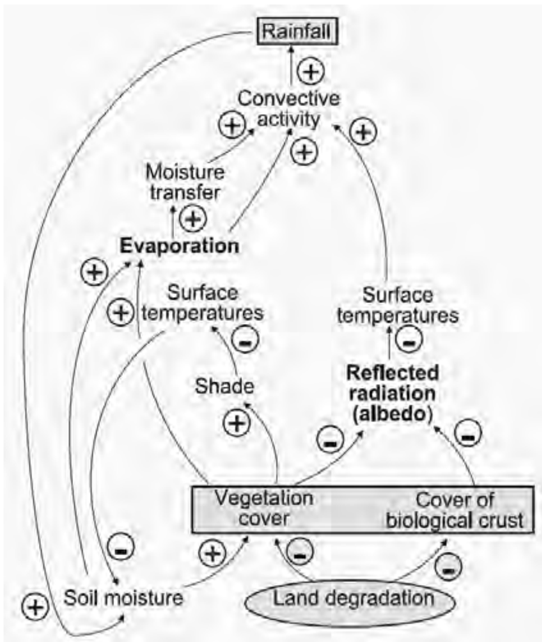


Illustration 11: Feedback cycles Land-Environment that amplify the climate change in the Sahel

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