Mistakes and Misunderstandings:

Use of Generic Structures and

Reality of Stocks and Flows

Prepared for the
MIT System Dynamics in Education Project
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1. INTRODUCTION

This paper studies two related mistakes and misunderstandings. First, it warns against the incorrect use of a generic structure. Secondly, it explains that stocks represent real-world accumulations and that flows represent changes over time in the stocks. This paper will examine two mistakes made in modeling a simple population of rabbits.

2. A FIRST ATTEMPT TO MODEL THE SYSTEM

A student decides to build a simple model in order to study how an area with limited resources affects the growth of a population. Initially, ample resources do not limit the exponential growth of the population. As the population grows, however, resources become more scarce, and the rate of growth slows. The population asymptotically approaches an equilibrium value.[1] The student expects the behavior of such a system to be S-shaped growth. Figure 1 shows a generic structure known to produce S-shaped growth.[2]

[1] The equilibrium value is known as the carrying capacity of the environment.
[2] For more information on generic structures producing S-shaped growth, please refer to: Terri Duhon and Marc Glick, 1994. Generic Structures: S-Shaped Growth I (D-4432), System Dynamics in Education Project, System Dynamics Group, Sloan School of Management, Massachusetts Institute of Technology, August 24, 30 pp.

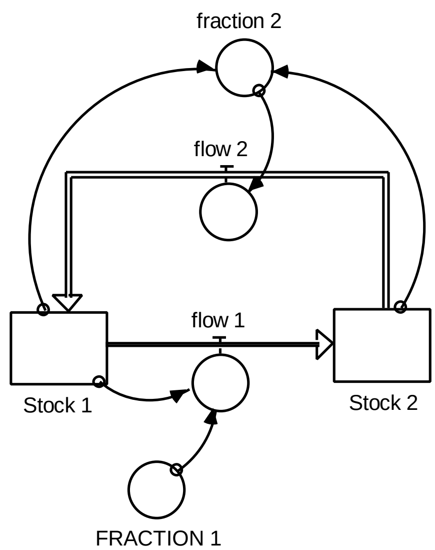

Figure 1: Generic structure producing S-shaped growth

The student applies the generic structure to model a rabbit population as shown in Figure 2. The model equations are in section 6.1 of the Appendix.

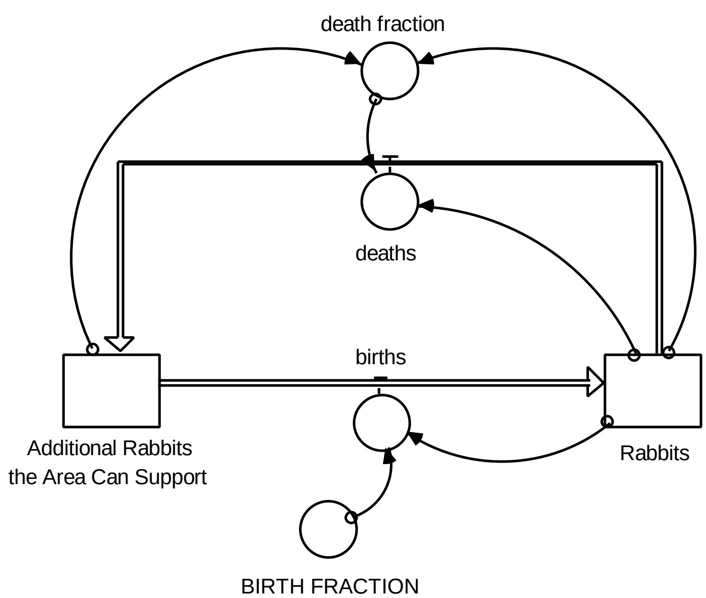

Figure 2: First model of the rabbit population

The model does indeed generate S-shaped growth of the "RABBITS" stock, as shown in Figure 3.

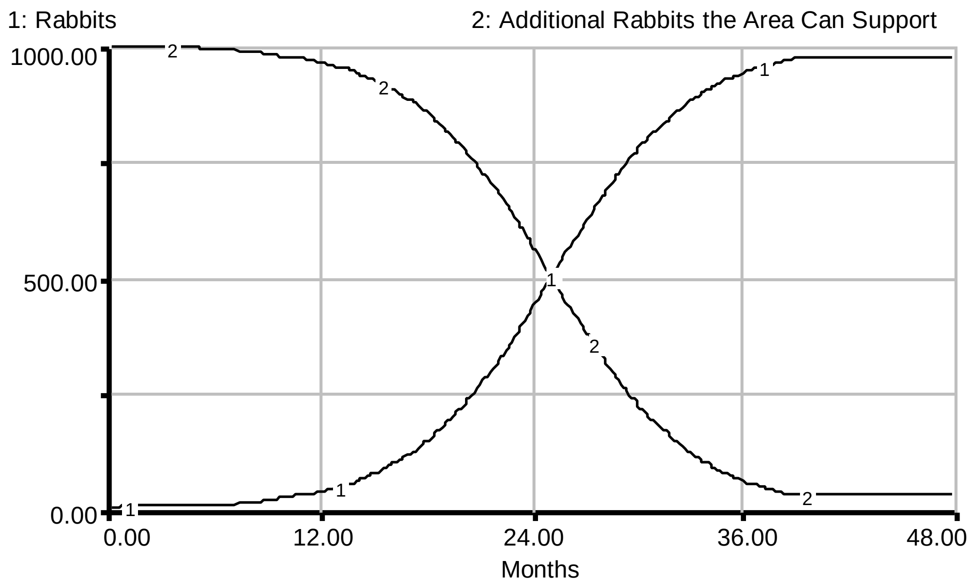

Figure 3: Stock behavior of the first model

3. MISTAKES AND MISUNDERSTANDINGS

Even though the model shown in Figure 2 generates S-shaped growth, it is not a realistic model. By simply fitting the system to a generic structure, the student did not realize that the structure does not represent the system.

One of the stocks, "Additional Rabbits the Area Can Support," is not an accumulation. The model implies that "Rabbits" are born from the stock of "Additional Rabbits the Area Can Support" through the flow of "births." Thus, hypothetically, a rabbit, before being born, exists as an additional rabbit. Likewise, "Rabbits" that die become "Additional Rabbits the Area Can Support" through the flow of "deaths."

The model in Figure 2 consequently suggests that a rabbit can exist in two states: either as a rabbit, in the stock of "Rabbits," or as an additional rabbit, in the stock of "Additional Rabbits the Area Can Support." In the real-world system, however, dead rabbits do not accumulate as additional rabbits, and additional rabbits are not reincarnated into rabbits. Such a formulation of the model is incorrect and does not represent the real system. The student must rebuild the model.

In addition, the formulation of the "death fraction" equation is implausible. With the initial values of the two stocks, the "death fraction" initially has the value of 1/2000 rabbits per rabbit per month, implying an average lifetime of a rabbit close to 167 years.

4. OVERCOMING OUR MISTAKES AND MISUNDERSTANDINGS

Figure 4 shows a corrected model of the rabbit population. Documented equations are in section 6.2 of the Appendix.

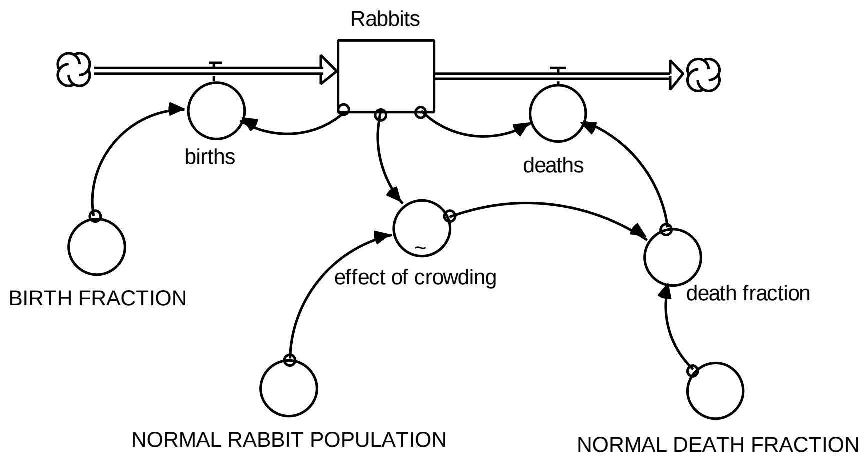

Figure 4: A corrected model of the rabbit population

In Figure 4, the total number of rabbits that the area can support is the converter "NORMAL RABBIT POPULATION." The model only contains one stock, "Rabbits," with an inflow of "births" and an outflow of "deaths." The "death fraction" is the product of a "NORMAL DEATH FRACTION" (set to be one third of the "BIRTH FRACTION") and the "effect of crowding." The "effect of crowding," shown in Figure 5, is a nonlinear function of the ratio of "Rabbits" to "NORMAL RABBIT POPULATION."[3]

[3] Further papers in the Mistakes and Misunderstandings series will explain how graph functions such as the "effect of crowding" should be constructed.

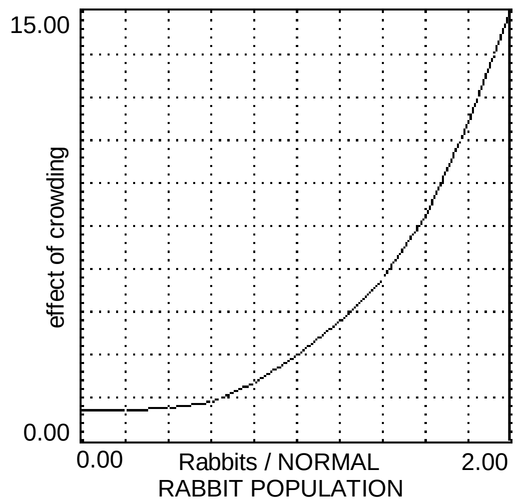

Figure 5: The "effect of crowding" graph function

The "effect of crowding" has a value of 1 when the population of "Rabbits" is low. The "effect of crowding" then increases to the value of 3 when the number of "Rabbits" is equal to the "NORMAL RABBIT POPULATION" (the ratio of "Rabbits" to the "NORMAL RABBIT POPULATION" is equal to 1).[4] Furthermore, the "effect of crowding" continues to increase if the ratio of "Rabbits" to "NORMAL RABBIT POPULATION" becomes greater than 1. Thus, when the ratio of "Rabbits" to "NORMAL RABBIT POPULATION" is 1, all resources are being used. The "effect of crowding" table function outputs a value of 3, and the "death fraction" is equal to the "BIRTH FRACTION." (Remember that "BIRTH FRACTION" is equal to three times "NORMAL DEATH FRACTION.") "Births" are then equal to "deaths," and the system stabilizes at equilibrium with 1000 "Rabbits."

[4] The value of 3 was determined by dividing the "BIRTH FRACTION" by the "NORMAL DEATH FRACTION."

The corrected model produces S-shaped growth, as shown in Figure 6.

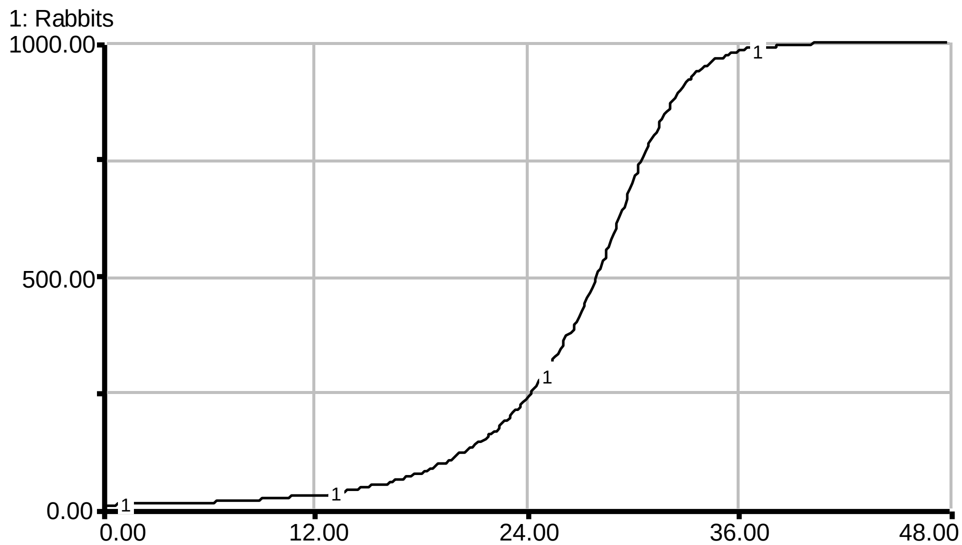

Figure 6: Behavior of the corrected model of rabbit population

The student did not make the modeling mistake because of a lack of knowledge about the system. Instead, the mistake resulted from an incorrect use of a generic structure. By simply applying the generic structure to the specific system, the student did not realize that one of the stocks used was not a real-world accumulation. Generic structures are useful, but a modeler should not adopt them blindly without considering the particular system being modeled.

The structure that was incorrectly used in the first rabbit population model can, however, be used in a variety of other situations. It could, for example, be used to model a market for a specific product, or the spread of epidemics. Nevertheless, it is not suitable to model the growth of a population within a restricted area.

The generic structure from Figure 1 contains two stocks that represent accumulations of the same units but in two different states. For example, in a model of the spread of epidemics (generating S-shaped growth), the two stocks would both represent people. One of the stocks would be "Healthy People," and the other stock would be "Sick People." The two flows, "infection rate" and "recovery rate" would then represent the rate of change of the people from the state of being healthy to the state of being sick, or vice versa. Figure 7 shows a possible epidemics model.[5]

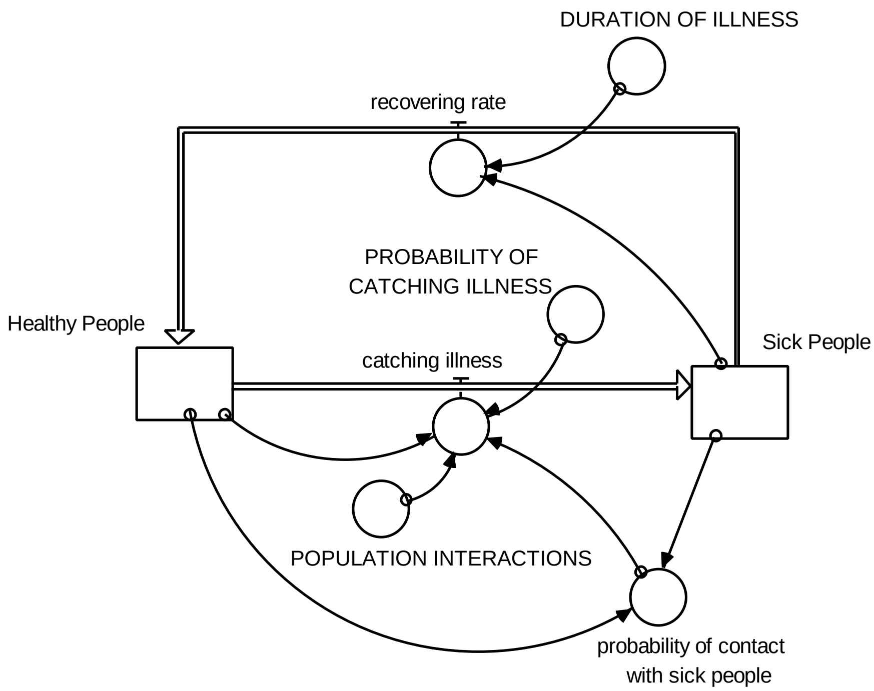

Figure 7: Epidemics model

On the other hand, rabbits in a population cannot exist in the two states of being either a rabbit or an "additional rabbit." Rabbits can be either living or dead. Dead rabbits, however, cannot become living rabbits again.

5. KEY LESSONS

When modeling, the modeler must keep in mind that stocks are accumulations within the system. Flows move real quantities to and from stocks, causing them to change over time.

More importantly, when modeling a system that exhibits a common behavior, the modeler should avoid incorrectly applying the corresponding generic structure. Not every

[5] The epidemics model is explained in more detail in Duhon and Glick, 1994.

system producing S-shaped growth, for example, can be modeled using every structure producing S-shaped growth. Instead, the modeler should first identify the stocks and flows in the system, then formulate a model that best represents the real-world system.

6. APPENDIX: MODEL DOCUMENTATION

6.1 First (Incorrect) Rabbit Population Model

☐ **Additional_Rabbits_The_Area_Can_Support(t)** =
Additional_Rabbits_The_Area_Can_Support(t - dt) + (deaths - births) * dt
INIT Additional_Rabbits_The_Area_Can_Support = 998
DOCUMENT: Additional number of rabbits that the area can support. It is equal to the maximum number of rabbits the area can support (1000) minus the current number of rabbits.
Units: Rabbits

INFLOWS:
deaths = Rabbits * death_fraction
DOCUMENT: Number of rabbits dying every month.
Units: Rabbits/month

OUTFLOWS:
births = Rabbits * BIRTH_FRACTION
DOCUMENT: Number of rabbits born every month.
Units: Rabbits/month

☐ **Rabbits(t)** = Rabbits(t - dt) + (births - deaths) * dt
INIT Rabbits = 2
DOCUMENT: Total number of rabbits in the population.
Units: Rabbits

INFLOWS:
births = Rabbits * BIRTH_FRACTION
DOCUMENT: Number of rabbits born every month.
Units: Rabbits/month

OUTFLOWS:
deaths = Rabbits * death_fraction
DOCUMENT: Number of rabbits dying every month.
Units: Rabbits/month

○**BIRTH_FRACTION** = 0.25
DOCUMENT: Number of rabbits born per rabbit per month.
Units: 1/month

○**death_fraction** = 0.25*Rabbits/(Rabbits+Additional_Rabbits_The_Area_Can_Support)
DOCUMENT: Number of rabbits dying per rabbit per month. It is equal to 25% of the ratio of rabbits to the maximum rabbit population.
Units: 1/month

6.2 Corrected Rabbit Population Model

□**Rabbits(t)** = Rabbits(t - dt) + (births - deaths) * dt
INIT Rabbits = 2
DOCUMENT: Total number of rabbits in the population.
Units: Rabbits

INFLOWS:
births = Rabbits * BIRTH_FRACTION
DOCUMENT: Number of rabbits born each month.
Units: Rabbits/month

OUTFLOWS:
deaths = Rabbits * death_fraction
DOCUMENT: Number of rabbits dying each month.
Units: Rabbits/month

○**BIRTH_FRACTION** = 0.3
DOCUMENT: Number of rabbits born per rabbit per month.
Units: 1/month

○**death_fraction** = NORMAL_DEATH_FRACTION * effect_of_crowding
DOCUMENT: Number of rabbits dying per rabbit per month.
Units: 1/month

○**NORMAL_DEATH_FRACTION** = 0.1
DOCUMENT: Number of rabbits dying per rabbit per month when there is no shortage of resources.
Units: 1/month

○**NORMAL_RABBIT_POPULATION** = 1000
DOCUMENT: Number of rabbits that the area can support under normal conditions.
Units: rabbits

∅ **effect_of_crowding** = GRAPH(Rabbits/NORMAL_RABBIT_POPULATION)
(0.00, 1.00), (0.2, 1.00), (0.4, 1.10), (0.6, 1.30), (0.8, 2.00), (1.00, 3.00), (1.20, 4.20), (1.40, 5.62), (1.60, 7.80), (1.80, 11.1), (2.00, 15.0)
DOCUMENT: Effect of the ratio of rabbits to the normal number of rabbits on the death fraction.
Units: dimensionless

Vensim Examples: Mistakes and Misunderstandings:

Use of Generic Structures and Reality of Stocks and Flows

By Aaron Diamond

October 2001

2. Rabbit Population

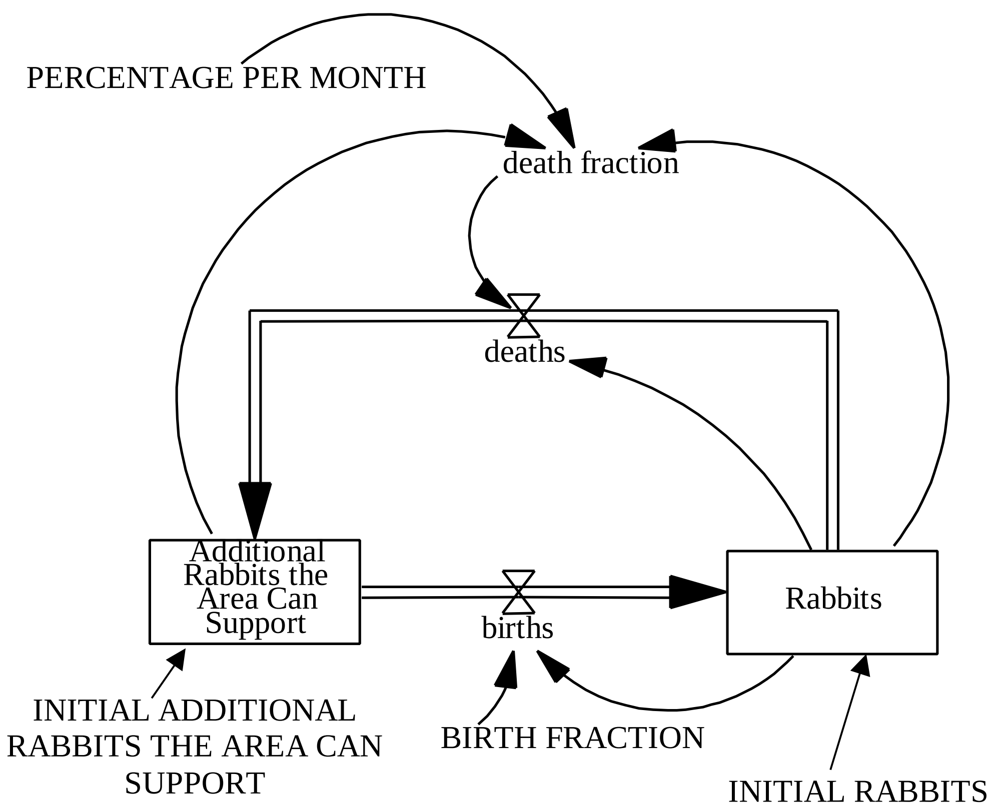

Figure 8: Vensim Equivalent of Figure 2: First model of the rabbit population

Documentation for First model of the rabbit population

(01) Additional Rabbits the Area Can Support= INTEG (+deaths-births, INTIAL ADDITIONAL RABBITS THE AREA CAN SUPPORT)

Units: rabbits

Additional number of the rabbits that the area can support. It is equal to the maximum number of rabbits the area can support (1000) minus the current number of rabbits.

(02) BIRTH FRACTION=0.25

Units: 1/Month

Number of rabbits born per rabbit per month.

(03) births=Rabbits*BIRTH FRACTION

Units: rabbits/Month

Number of rabbits born every month.

(04) death fraction=PERCENTAGE PER MONTH*Rabbits/(Rabbits+Additional Rabbits the Area Can Support)

Units: 1/Month

Number of rabbits dying per rabbit per month. It is equal to 25% of the ratio of rabbits to the maximum rabbit population.

(05) deaths=Rabbits*death fraction

Units: rabbits/Month

Number of rabbits dying every month.

(06) FINAL TIME = 48

Units: Month

The final time for the simulation.

(07) INITIAL ADDITIONAL RABBITS THE AREA CAN SUPPORT= 998

Units: rabbits

(08) INITIAL RABBITS= 2

Units: rabbits

(09) INITIAL TIME = 0

Units: Month

The initial time for the simulation.

(10) PERCENTAGE PER MONTH= 0.25

Units: 1/Month

25% of the ratio of rabbits to maximum rabbit population is used to calculate the death fraction.

(11) Rabbits= INTEG (births-deaths, INTIAL ADDITIONAL RABBITS)

Units: rabbits

There are initially two rabbits in the population.

(12) SAVEPER = TIME STEP

Units: Month

The frequency with which output is stored.

(13) TIME STEP = 0.0625

Units: Month

The time step for the simulation.

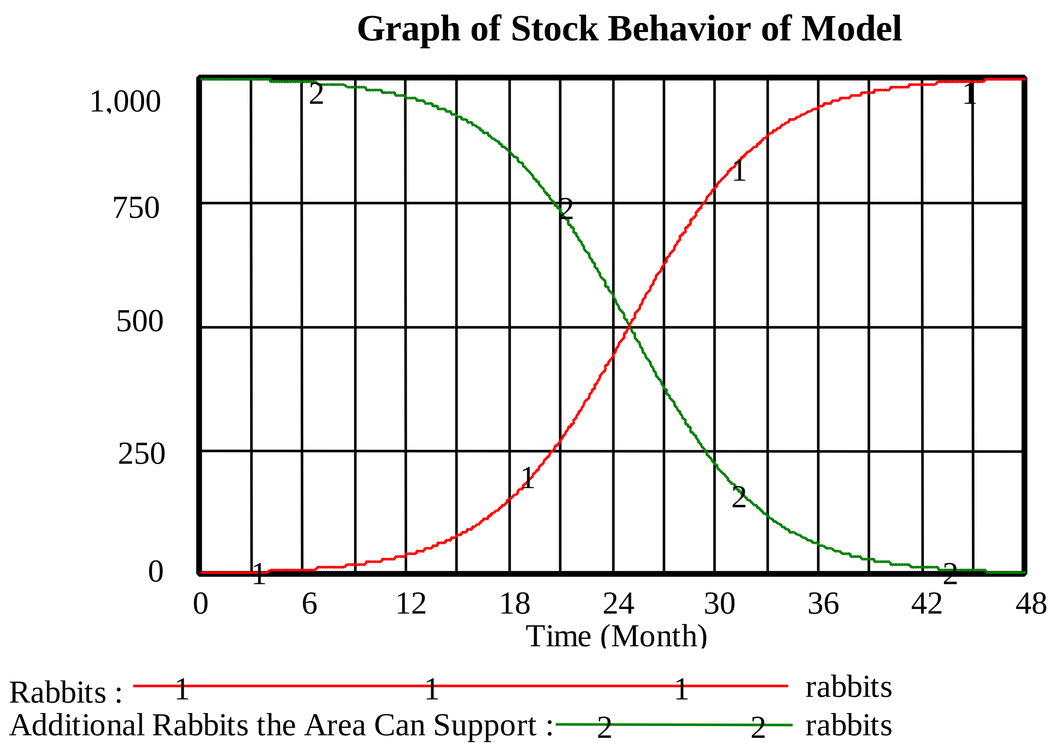

Figure 9: Vensim Equivalent of Figure 3: Stock behavior of first model

4. Overcoming Our Mistakes and Misunderstandings

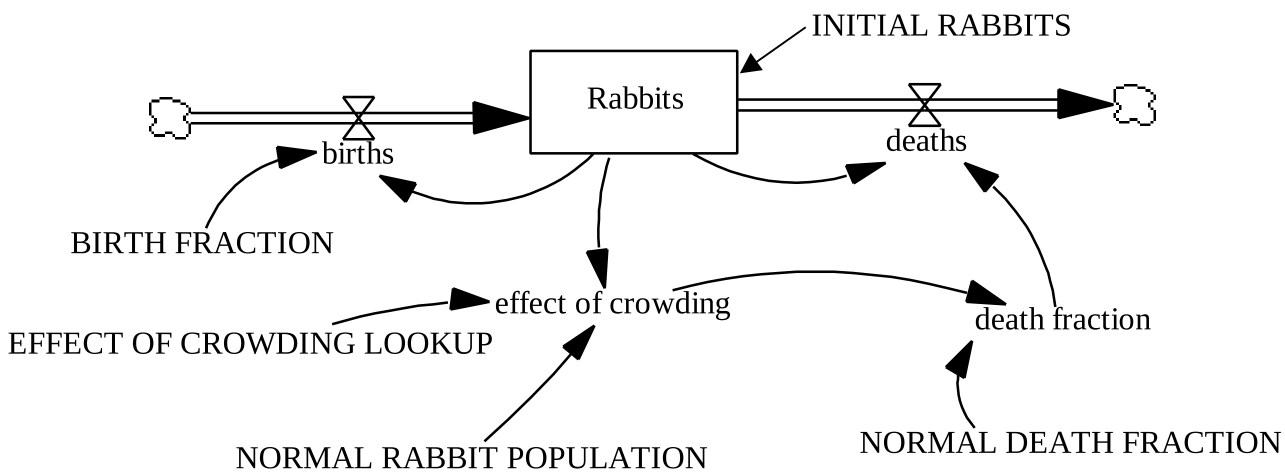

Figure 10: Vensim Equivalent of Figure 4: A corrected model of the rabbit population

Documentation for corrected model of rabbit population

(01) BIRTH FRACTION=0.3

Units: 1/Month

Number of rabbits born per rabbit per month.

(02) births=Rabbits*BIRTH FRACTION

Units: rabbits/Month

Number of rabbits born each month.

(03) death fraction=NORMAL DEATH FRACTION*effect of crowding

Units: 1/Month

Number of rabbits dying per rabbit per month.

(04) deaths=Rabbits*death fraction

Units: rabbits/Month

Number of rabbits dying each month.

(05) effect of crowding= EFFECT OF CROWDING LOOKUP (Rabbits/NORMAL RABBIT POPULATION)

Units: dmnl

Effect of the ratio of rabbits to the normal number of rabbits on the death fraction.

(06) EFFECT OF CROWDING LOOKUP=([(0,0)(10,20)], (0,1), (0.2,1), (0.4,1.1), (0.6,1.3),(0.8,2),(1,3),(1.2,4.2),(1.4,5.62),(1.6,7.8),(1.8,11.1),(2,15))

Units: dmnl

(07) FINAL TIME = 48

Units: Month

The final time for the simulation.

(08) INITIAL RABBITS=2

Units= rabbits

(09) INITIAL TIME = 0

Units: Month

The initial time for the simulation.

(10) NORMAL DEATH FRACTION=0.1

Units: 1/Month

Number of rabbits dying per rabbit per month when there is no shortage of resources.

(11) NORMAL RABBIT POPULATION=1000

Units: rabbits

Number of rabbits that the area can support under normal conditions.

(12) Rabbits= INTEG (births-deaths, INTIAL RABBITS)

Units: rabbits

Total number of rabbits in the population.

(13) SAVEPER = TIME STEP

Units: Month

The frequency with which output is stored.

(14) TIME STEP = 0.0625

Units: Month

The time step for the simulation.

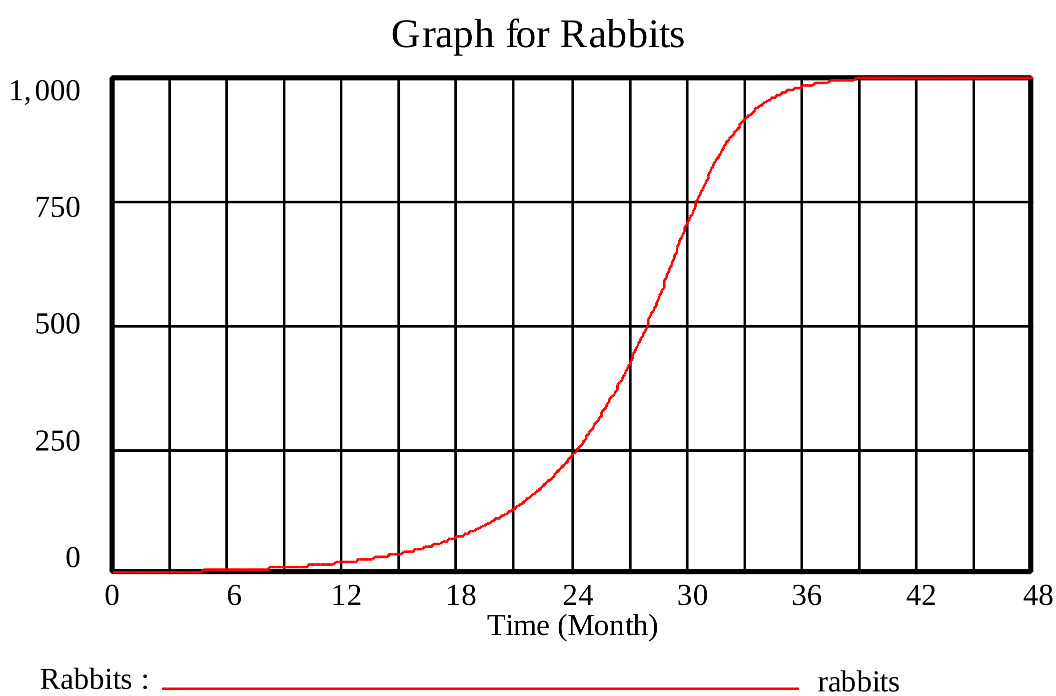

Figure 11: Vensim equivalent of Figure 6: Behavior of the corrected model of Rabbit population