Introduction and problem formulation

According to the 4th IPCC report on Climate Change Effects, the situation of increasing salt intrusion in coastal aquifers and emigrants from the land are happening in parallel for a certain reasons. This observation led to the creation of new term "climate refugees" with an implication of a causal relationship between climate change and people lives. While looking into more details, they recognize some connections linked those 2 issues. For example: the increase of population will rise up the demand for food, which indirectly enlarges the need for agriculture land and water for irrigation which being pumped from the aquifer layer. However, due to the limitations of water source and available land, those demands could not be satisfied at their required levels. As the result, the shortage of food could occur which in the end augments the hungry people who afterwards must leave the country. Therefore, via the example, we see that though individual phenomenon was relatively revealed, those inter-constraints still point to a complex issue that needs to be understood and unbundled from overview position.

With the above intention, a model with capability of capturing the core of salt – emigrant problem from a big-picture vision will be potential solution. The core of problem here must encompass the ongoing long-term time span of 30 – 50 years; all of processes that relate to water, land, food and their surrounding natural elements; and obviously all human actors involved. To some other aspects, this problem is dynamic because it happens in a context where the present contains echoes of the past, today constitutes tomorrow. Moreover, to some extent, thanks to many scientific researches that have been conducted, the targeting problem will not be a total black box but a (relatively) white box with enough available data. Furthermore, based on that primitive model and a firmer understand of current problem, some policies are draw to support strategically the decision making process. Hence, by having to reflect all the continuous, dynamic, multi-actors and inter-process characteristics of salt-issue, the chosen model should be formulated in the methodology of system dynamics (SD).

In brief, a SD model would be built to answer the main research questions:

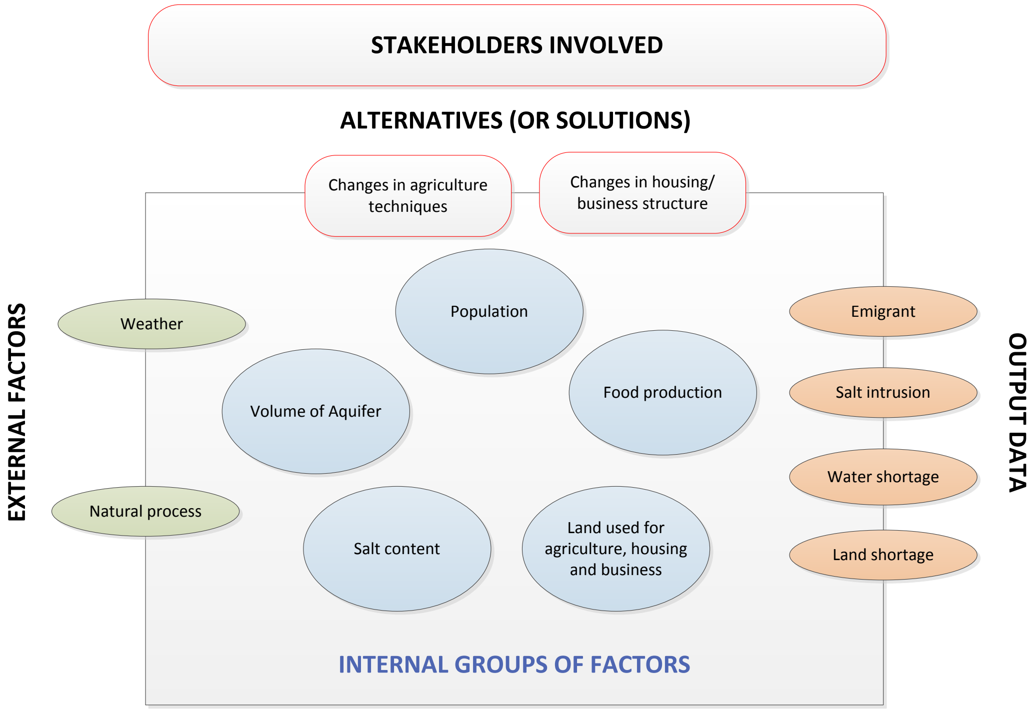
- *What is the concrete relationship between the intrusion of salt in the coastal aquifer and the number of emigrants in the country in respect to time?*
- *Is there any feasible measure or group of measures to a future in that intrusion of salt is prevented the while the emigrant is kept decreased or at least not increased?*
    - *What steps must be done?*
    - *For how long (years) will solution be effective?*
    - *Who (among actors involved) will be responsible for what tasks?*

Problem decomposition

The research questions must be answered by decomposing the problem into a limited number of certain elements, categorizing them into external and internal factors, policies and actors involved.

- First, there are 5 groups of internal factors that belong to and help to understand the internal mechanism of problem: Population, Volume of Aquifer, Food production, Salt content and Land use. Though some among those factors could have social qualitative properties, all of them must be quantized enough to let the SD model run.

- Second, there are 2 external factors that modeler could not change: Weather and natural process – which means they are viewed as input data.
- Third, by intuitive analysis and experience, 2 groups of solution are probably helpful: Changes in agriculture techniques and changes in housing/business structures. These suggested solutions do not limit the opportunity of providing other solutions when model is researched in details.
- Finally, with all given data and factors, it needs to have 4 output data to evaluate the efficiency of applied policies: Emigrant (people), Salt intrusion (length of coastal aquifer), Food shortage (kg crops difference between demand and supply of food) and Land shortage (meter square difference between demand and supply of land use for housing and business).

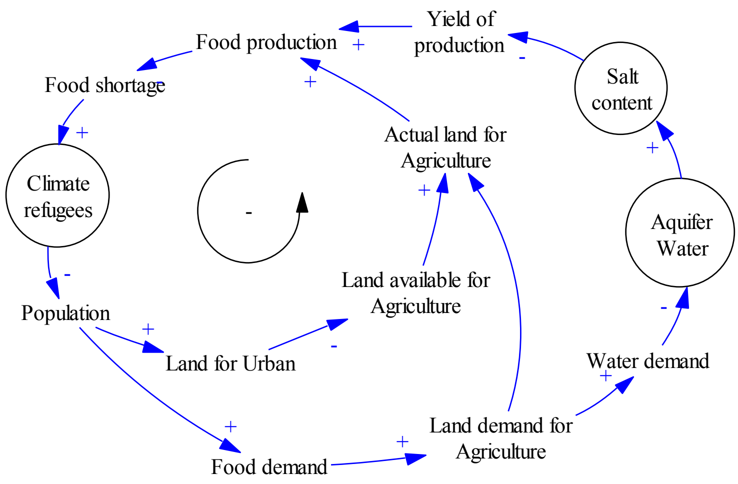


Causal loop diagram and SD model specification

Starting from problem description and common sense understanding, the 1st version of causal loop diagram (CLD) is drawn. Even though this 1st CLD could be changed completely after the modeling process finishes with more data and more emerging results, it still is very helpful in the sense of general guidance. This general guidance is illustrated by 2 closing loops:

- 1st loop start from population increase that leads to demand for urban land, then limits the land for agriculture purpose, which means decrease the food productions and increase the food shortage, ends with the decrease of population.

- The 2nd loop is an extended version of 1st loop, but goes through the increased demand for water which pushes up the required water from aquifer, then increases the salt concentration and decrease the yield of production. Both of two loops are negative. This situation signals that the increase of factors' values in one loop is not always in the same direction.



About the SD model specification:

- the time span would correspond to that provided data of river flow upstream extraction, which means from year 1975 till year 2020 (or 0 to 45). This time span is long enough to have enough data from the past, and far enough from the present to get a long-term results. Moreover, this long time span also helps the validation steps by using the current data to build the model and the past data to verify (or valid) the model. Time unit is year. Time step could be the minimum value provide by Vensim, but is chosen at 0.0625 – not too big to have a smooth result, and not too small to make a computational burden on Vensim.

- Models have 6 parts: Population, Volume of Aquifer, Water demand, Salt content, Crops production and Land use. Each of this part would be elaborated in next sections.

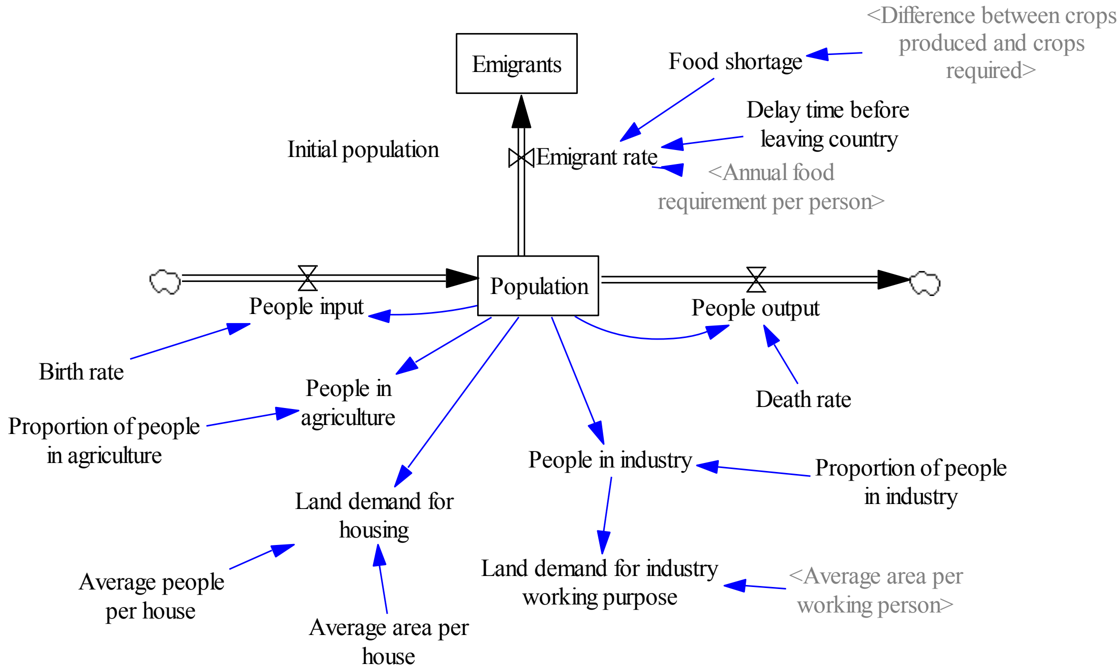
Model building parts

Population

In this part, "*Population*" (people) is the stock variable whose input rate is "*People input*" (people / year) and output rate are "*People output*" (people / year) and "*Emigrants*" (*people/year*). The "*People input*" is calculated by the multiplying the given data "Birth rate" (4-6 %/year) with "Population". The "*People output*" is calculated by the multiplying the given data "*Death rate*" (5.5 %/year) with "*Population*".

There is one assumption needed to calculate the "*Emigrant rate*": parameter "*Delay time before leaving country*" (year). This assumption assumes that the ones who lack of food, would leave the country after a certain delay time (1, 2 or more than 3 years). So we use "Food shortage" (difference between crops produced and crops required), "*Annual food requirement per person per year*" (kg/person/year) and parameter "*Delay time before leaving country*" to get "*Emigrant rate*".

The initial value of Population is about half of millions of people, the Birth rate is almost same to Death rate, which means the only thing counted here is the Emigrant rate. Therefore, in a range of reasonability, the population should be stable for the modelling period; a change within ± 20 – 30% might be accepted.



The Population part is an important data to calculate the "People in agriculture" (people), "People in industry" (people). And from those data, we could calculate the "Land demand for housing" (m2), "Land demand for industry working purpose" (m2) by other given factors like "Proportion of people in agriculture" (22%), "Proportion of people in industry" (12.5% of 78%), "Average area per working person", (50 m2/person) "Average people per house" (7 people/house), "Average area per house" (285 m2/house).

Therefore, population will influence the land demand and food demand in direct proportional direction, while it is influenced by food shortage in reverse direction.

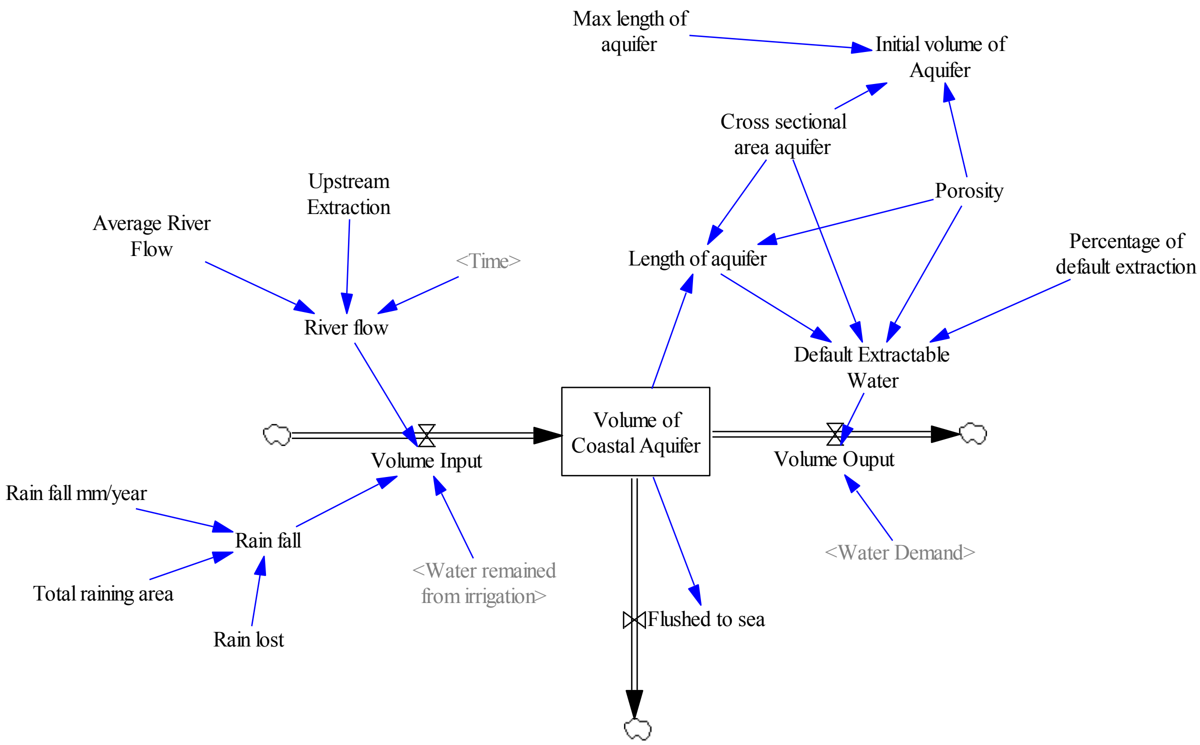
Volume of Coastal Aquifer

In this part, "*Volume of Coastal Aquifer*" (m3) is the stock variable whose input rate is "*Volume input*" (m3/year) and output rate are "*Volume output*" (m3/year) and "*Flushed to sea*" (*m3/year*).

The "*Volume input*" is calculated by 3 sources:

- The "*River flow*" (m3/year) with "Average River Flow" (m3/year) and "Upstream Extraction" (%). The "Average River Flow" is a constant of 2 x 106 m3/year, but "Upstream Extraction" will be presented in form of "look up" function, x-axis is time frame (from 0 – 45), y-axis has value provided by research about how percentage of river water comes back to aquifer.
- The "*Rain fall*" (m3/year) with "Rain fall mm per year" (mm/year), "Total raining area" (m2) and the "Rain lost" (%). All of those factors are constant and given beforehand.
- The "*Water remained from irrigation*" (m3/year) which is calculated by water extracted for irrigation and the percentage of remaining.

The "*Volume output*" is the minimum function between 2 operators: "Water demand" (m3/year) and "Default Extractable Water" (m3/year) (the maximum available water from Aquifer that people could get).



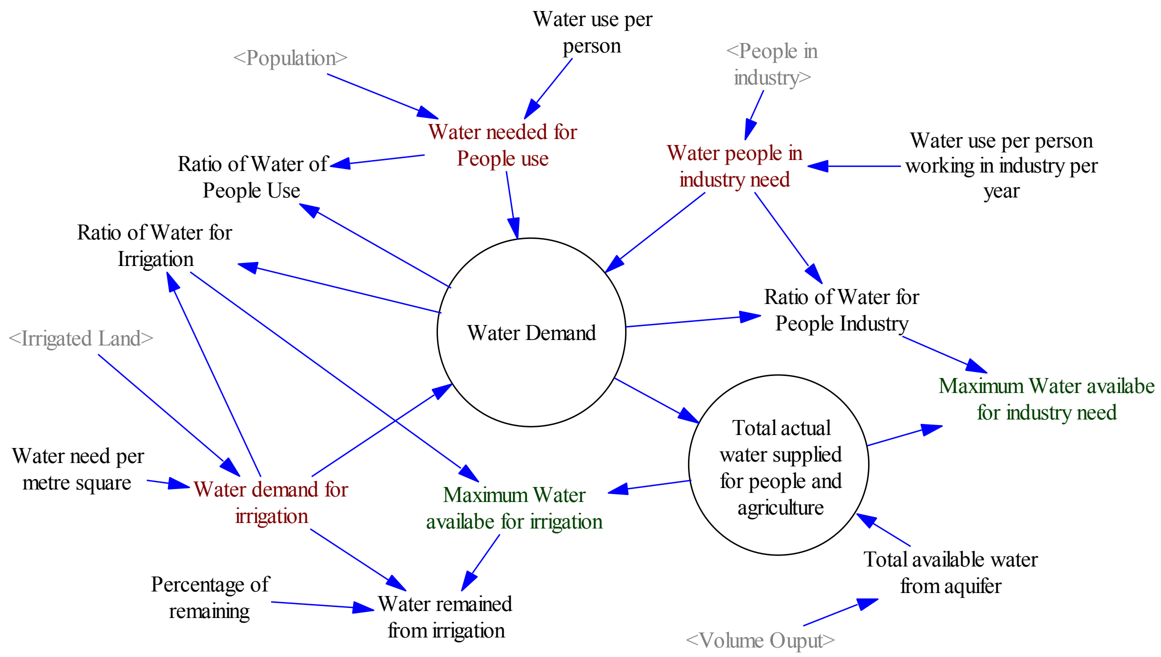
The "Volume of Coastal Aquifer" has an initial value of meter cube of water which also is the maximum value of water capacity. If added water from rain, river or flood comes to the aquifer and get over that threshold, that additional exceeded water will flush to the sea. The "Volume of Coastal Aquifer" will influence the water available for agriculture and other social activities of people in proportional direction, and is influenced by water used for irrigation in reverse direction.

Water demand vs. Water used

The water part addresses the serious conflict between the limited water available and the enormous demand for water. There is no stock variable in this part, only auxiliary variables and given constant. For example:

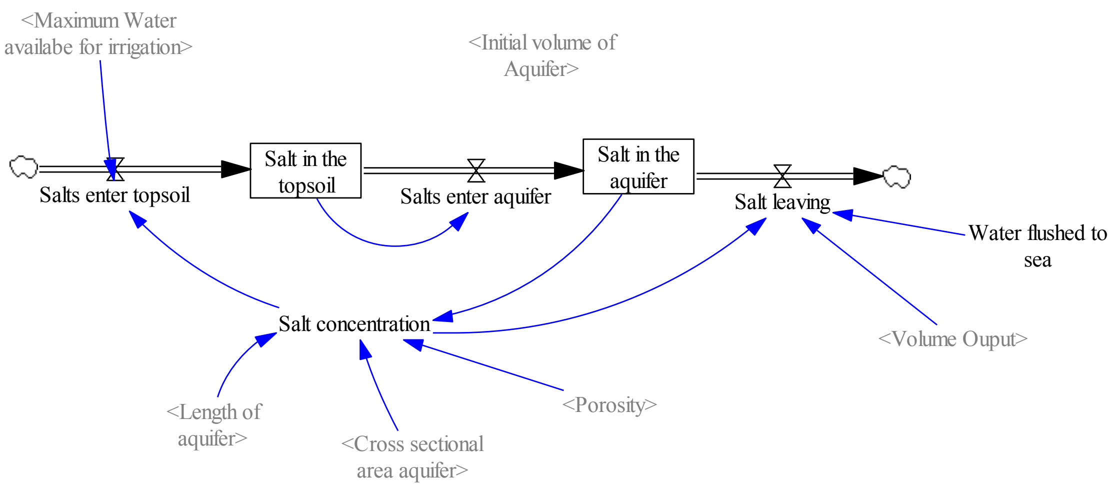
- The Water Demand is the sum of Water demand for irrigation, Water need for people use, and Water people need in industry. In general, this variable depends positively on Population and its professional proportion.
- The Total actual water supplied for people and agriculture is get by the minimum function between Water Demand and Water available from aquifer.

To make the model simple, the possibility of importing maximum 10% water demand is removed, or left to the policy part.

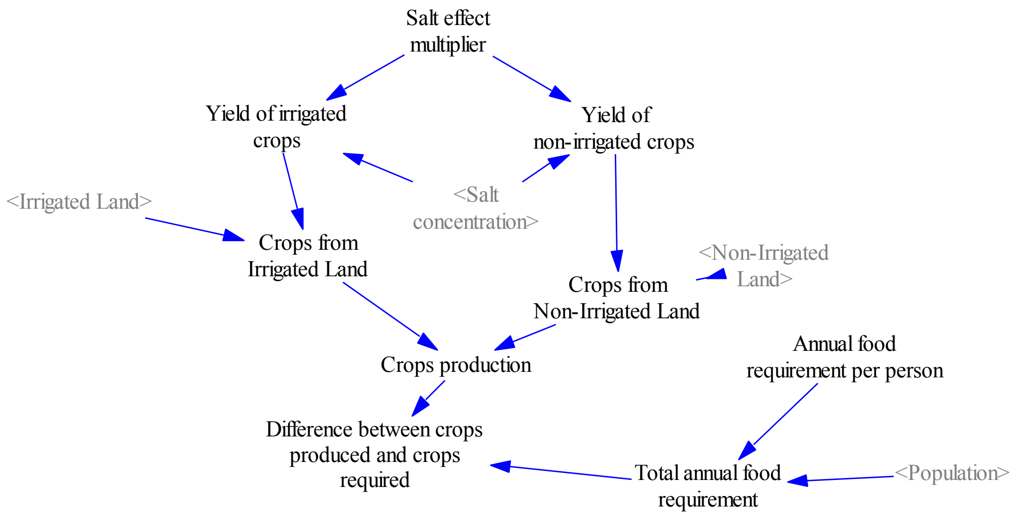


Salt content

There are 2 stock variables in this part: Salt in the topsoil and Salt in the aquifer. The model shows that: Salt has always existed in the aquifer, its change of number happens due to the salt leaving to sea and salt leaving via bump for irrigation or other human needs. The salt leaving via irrigation will come to the topsoil, and then return back to the aquifer via the irrigation water.



The most important factor in this part is the salt concentration because it has connection to the yield of irrigated and non-irrigated crops, which means impacts on the crops productions, difference between food demand and food supply, i.e. food shortage.



Land use (for agriculture, housing and business)

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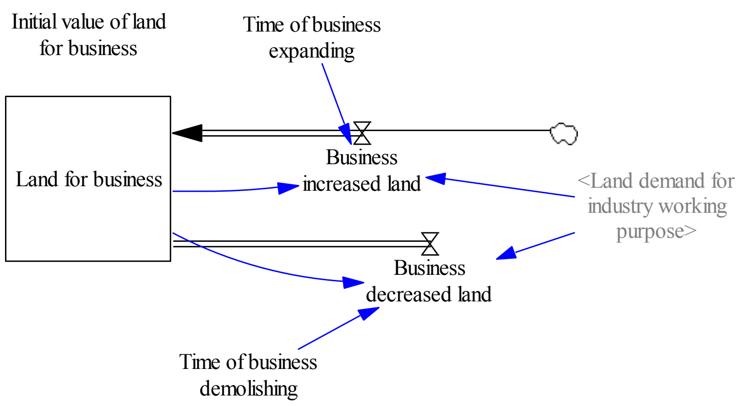
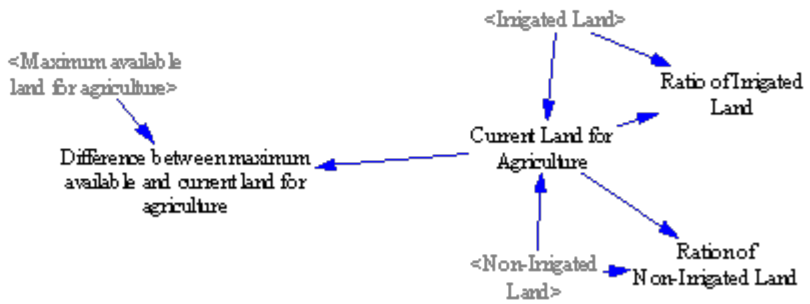
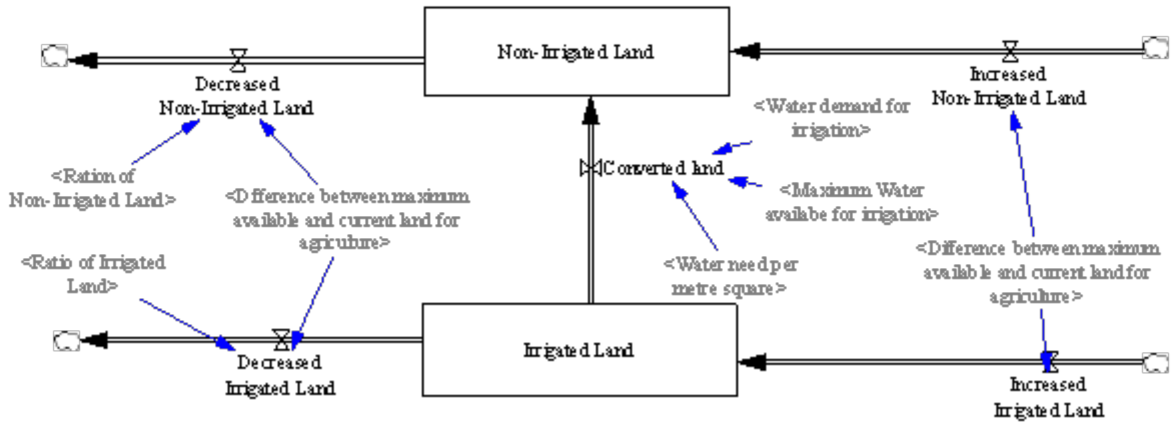
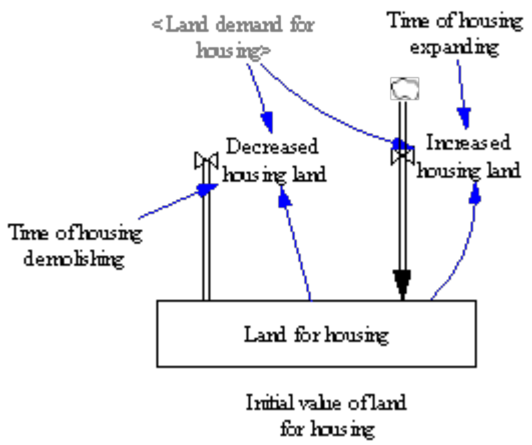


This is the largest part of the whole SD model which contains the small model of Land for business, Land for housing, Irrigated Land and Non-Irrigated Land.







Conclusion

The model is still at the basic concept. it runs but still gives illogical data graph. Many details are mentioned in the problem description but have not been embedded in the model yet. About the structure of modeling process, the validation, verification and sensitivity analysis are still missing. Even though, most of important factors could be found in the model whose current simple version (causal loop diagram and Vensim model) is relatively enough for understand the structure of addressing problem.

For the next steps, some misunderstanding of natural processes in aquifer (especially the ones relate to aquifer composition and salt content) must be cleared first. Then each sub-model must be completed by some really simple assumptions or constants. Finally, the steps of validation, verification and sensitivity analysis must be conducted to test the logicality of outcomes and the importance of roles of some parameters in the models.