A System Dynamics Approach in Water Resource Management and Government Subsidy Policy: A Case Study of Tajan Basin in Iran

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Abstract:

After announcing the fuel rationing policy in 2008, government decided to eliminate subsidies in order to manage consumption of natural resources. Thus, a cashing subsidy policy has been applied since end of 2010. In first stage, different kinds of energy and resources like water were considered. Government's plan was to pay subsidies directly to consumers.

In this paper, we focused on the consequences of removing water subsidy in Tajan, an area in the north of Iran. We modeled different ways of water supply and demand in Tajan by concepts of system dynamics. We tried to show the effects of cashing subsidies policy in municipal demand of water in Tajan and examined two kinds of implementing this policy. In the first strategy, water price is increased smoothly over modeling horizon which is considered to be 24 months. While in the second one, price is increased suddenly in the first month, exactly similar to the way the government has done. We designed third strategy in which no subsidy elimination happens and prices increase according to inflation. A water surplus indicator was considered for comparing these strategies which was calculated by decreasing water supply from its demand. First strategy was shown to be best one.

1. Introduction

Iran is one of the richest countries in natural resources and one of the few countries that different seasons can be seen in its various geographical regions. Managing these natural resources in order to become useful for people is a time consuming procedure needs a huge amount of capital and a precise planning. Taxes and subsidies are two types of methods help government handle it.

A subsidy (also known as a subvention) is a form of financial assistance paid to a business or a specific economic sector. In Iran subsidies are dedicated to most of the strategic goods such as rice, wheat, oil and some of the important services by the government. So, many of the goods or services cost much more than its price. This matter as expected isn't a suitable way for preparing a general welfare for people in a long time because of different reasons such as restricted natural resource and considering needs of future generations.

So, Iran's government decided to cash subsidies and bring back the real price of goods from the beginning of 2011. Their good experience in fuel rationing in 2008 and devastating condition after global sanction against Iran were other major reasons obliged the government to plan this economical surgery.

As the first stage of this huge economical revolution, different kinds of energy and public needs like water were considered. Government planned to eliminate subsidy of water and instead of that, they tried to bring back the subsidy cashes to people directly. But one of the most important questions that may be asked in this regard is strategy of increasing the price of water to implement the policy. Since these goods have a vital role in the life of people, increasing of their prices should be done carefully. It must be determined that how much increases should be done in a specific period. This is exactly what we are seeking in this paper.

In this paper, we focused on the consequences of removing water subsidy in Tajan, an area in the north of Iran. By modeling different sources of water supplies and demands in Tajan, we started to design a system dynamics model. The main water source in Tajan is rivers and one of the vital demand sections is municipal demand. We tried to show the effects of cashing subsidy policy in municipal demand of water in Tajan. Three pricing strategies developed. In the first strategy, water price is increased smoothly over modeling periods which is considered to be 24 months. While in the second one, price is increased suddenly in the first month, exactly similar to what the government has done. In the last one, we considered situations in which no elimination happens and the price increases according to its regular inflation. A water surplus indicator was considered for comparing these strategies which was calculated by decreasing water supply from its demand.

According to local observation, as a critical and important assumption, we assumed that the most important demand section that is affected by cashing subsidy policy for water in Tajan,

was municipal demand and other sections such as industrial and agricultural demand were not affected very much by implementing this policy.

In the next sections of this paper, first we will mention the main characteristics of the study area and depicted a general view of it. Then the problem is explained and a model is developed by the concepts of system dynamics for this problem. We tried to describe our model by using causal diagrams. In the third section, flow diagrams are designed and their features are explained.

1.2 Study Area

In this paper, we concentrate on supply and demand of water in a specific area in Iran. Tajan is an area in the North of Iran with about 460000 inhabitants and at list 60 percent of them work on farms. Cashing subsidies policy in this area, certainly effects on people in obviating their daily water needs.

Tajan area is more than 90940 hectare. It is bounded from east to Neka river, west to Siyahrood river, north to Mazandaran sea (Caspian sea) and sought to Elborz mountains .This system is in 53° 15' to 52° 53' of geographical longitude and 36° 25' to 36° 50' of latitude and is contained of some important cities such as Sari, center of Mazandaran province, Neka, one of the biggest center of electricity generation in Iran and Ghaemshahr, one of the most important commercial city in north of Iran. Its fertile soil makes a proper situation for growing different crops such as water melon, peach, orange and rice. Different industries are also located in this area like milk and meat producers. So, this system is important from several agricultural, industrial and population-based aspects.

A lot of small and some big rivers are flowing in this system, but four of them are more important than others. These rivers are: Tajan, Darabkala, Syahrood and Neka that are shown in Figure 1. In this figure, the boundaries of Tajan are obviously illustrated.
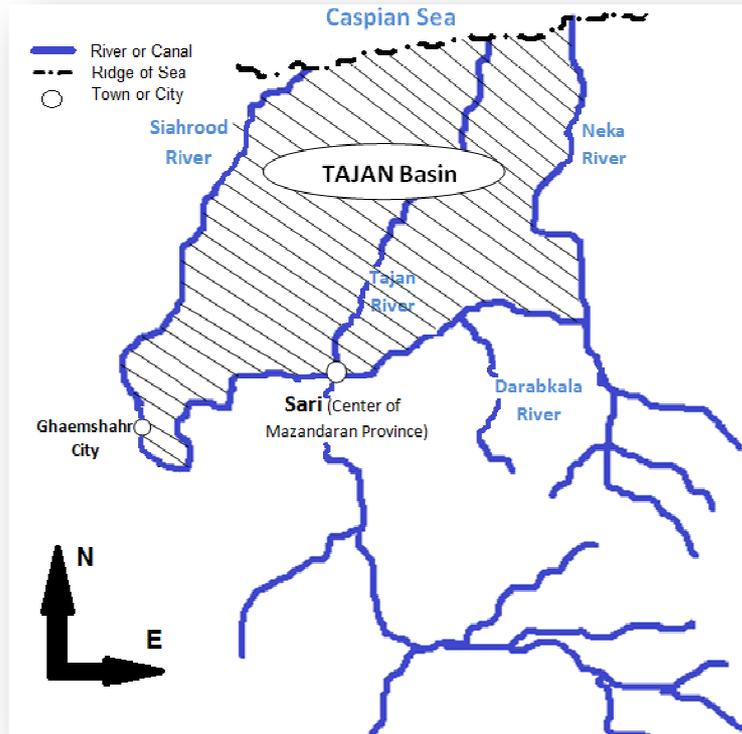
Figure 1. Map of Tajan.

In this paper, what we tried to show was the effects of cashing water subsidies on surplus supply of water in Tajan system in a planning interval which was 24 months. Each month was considered as time unit. So, we divided the planning horizon into months and calculated the surplus supply water indicator for each month by implementing each of three strategies.

2. Model Description

As we explained in the introduction, we wanted to develop a system dynamics model to simulate surplus supply water according to different sources of water supply and by considering the changes in amount of demand of different sections which have happened because of increasing in water price according to governmental new policy in cashing water subsidy in Tajan.

2.1 Subsystems

There are two main subsystems in our model which are supply and demand. Each of them has specific features are explained here.

2.1.1 Supply

As we wanted to assess the effect of cashing subsidies in surplus water in municipal demand section, at first we should find the source of water supply in Tajan.

In Tajan system, there are five sources of water supply: rivers, shafts, dykes, return flows and springs. In modeling the problem, we must know the supply sources of municipal demand. In this area, municipal and industry demand are supported by rivers. Most important rivers in Tajan are: Tajan, Darabkola, Neka and Siyahroud. The average flow of these rivers in a year per month is showed in Table 1.

Table 1. Average flow of water for each river per month (mm^3)

River	Farvardin (Mar-Apr)	Ordibehesht (Apr-May)	Khordad (May-Jun)	Tir (Jun-Jul)	Mordad (Jul-Aug)	Shahrivar (Aug-Sep)	Mehr (Sep-Oct)	Aban (Oct-Nov)	Azar (Nov-Dec)	Dey (Dec-Jan)	Bahman (Jan-Feb)	Esfand (Feb-Mar)
Tajan	30.58	23.65	17.86	14.27	11.62	14.19	14.98	13.3	13.63	13.63	14.36	19.76
Siyahroud	5.44	3.4	1.71	1.42	1.23	1.96	2.36	2.82	3.21	3.5	4.17	5.21
Darabkola	1.82	1.1	0.5	0.29	0.27	0.35	1.04	1.01	1.43	1.24	1.92	2.1
Neka	29.7	14	5.65	3.05	2.73	5.01	8.94	11.56	13.09	13.76	17.18	25.45

In Figure 2, flows of rivers are illustrated to give an understandable view of them. In our model, as we discuss next, drought rate, raining rate, sediment of water in earth and other factors that affect rivers water are considered in primary data. Although our planning horizon is not very long, because of sudden climate changes in some years, we proposed an over drought rate and we set its value to be 5%. The influence of this small amount in final results was not deniable.
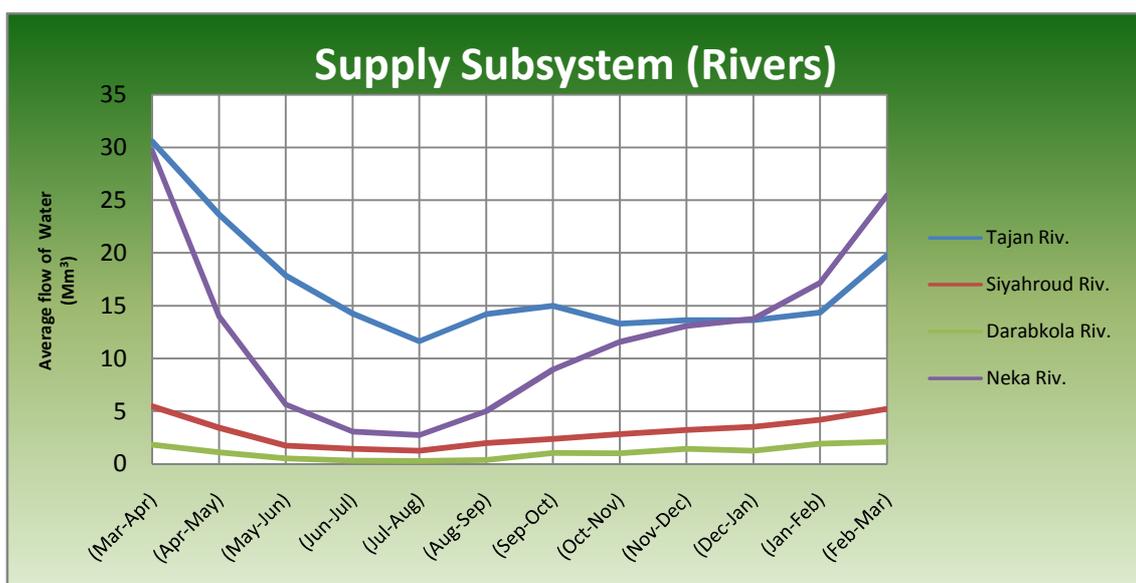

Figure 2. Diagram of flows of 4 rivers in a year

2.1.2 Demand

In this system we have three kinds of demand: industry, agriculture and municipal. Rivers in Tajan contribute in situations that can support all kinds of demand. But, they have a key role in municipal and industrial demand sections because these sections don't have any other sources for supplying their needs to water. In this part of the paper, first we tried to find water needs of the agricultural demand section and then municipal demand is explained by considering a classical theorem. At last, industry demand is discussed. We set a fix value for this demand in all periods of modeling horizon.

- *Agriculture Demand:*

  Farms in Tajan, are irrigated from two kinds of supplies on the bases of their irrigation methods. We named the first kind of irrigation, in-net irrigation or inside modern net which is referred to new and modern methods of irrigation. Traditional irrigation system is the second kind of irrigation in which farms are irrigated by using inefficient methods. Areas of lands that irrigate by in-net and out-net irrigating systems are 34225 and 29575 hectares respectively. Meanwhile, average amount of usable rivers water for irrigating farms of Tajan by using each of these two kinds of irrigation are shown in Table 2. As it is obvious, rivers are used in springs and summers and in the other seasons, raining is enough for irrigation.

Table 2. Average distribution of agricultural demand in month (m^3/hec)

Kind of Irrigation	Farvardin (Mar-Apr)	Ordibehesht (Apr-May)	Khordad (May-Jun)	Tir (Jun-Jul)	Mordad (Jul-Aug)	Shahrivar (Aug-Sep)	Mehr (Sep-Oct)	Average in Year
Inside modern net	1605	2065	1882	1958	1297	59	0	8866
Outside modern net	1501	1946	1591	2116	1488	53	0	8694

For a better understanding of two different kinds of irrigation during a year, we illustrated their monthly values in Figure 3.
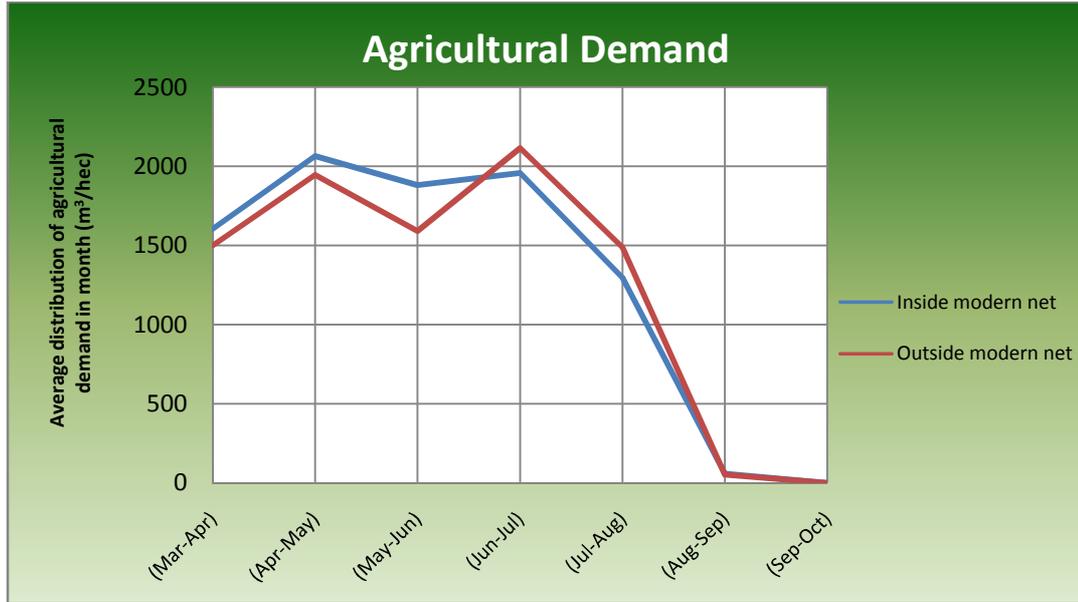
Figure 3. Diagram of Agricultural Demand

- *Municipal Demand:*

We calculate the demand of people in this system from well known formula of elasticity:

$$E = \frac{\%\Delta Q}{\%\Delta P} = \frac{Q_t - Q_{t-1}}{P_t - P_{t-1}} \cdot \frac{P_{t-1}}{Q_{t-1}} = \frac{P_{t-1}}{P_t - P_{t-1}} \cdot (\frac{Q_t}{Q_{t-1}} - 1)$$

(1)

$$\Rightarrow Q_t = Q_{t-1} \cdot \left(1 + E \cdot \frac{P_t - P_{t-1}}{P_{t-1}}\right)$$

In which E is elasticity, Q_t is the amount of demand in period t and P_t is price of municipal water in period t. It should be noticed that price of purified water for municipal consumptions differs from price of water in other sections. Also, it must be considered that there is a minimum need for municipal water demand. As we know, usually increasing of price leads to decreasing of demand. In fact, consumption of water for everybody can't come down from a critical limit in a time unit even if its price is very high at that time. Therefore, municipal demand should be calculated as follow.

$$Demand_t = Max \{ Q_t \text{ , minimum demand of people in period } t \} \qquad (2)$$

In order to obtain minimum demand of people in period t, we assumed the average of minimum water consumption of a usual person in Iran is 140 liters per day (surely this parameter is lower than 140 in developed countries). So, minimum municipal demand in a month is calculated as follow.

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$$minimum\ demand\ of\ people\ in\ period\ t = [(POP_t \times 140)/(1000 \times 30)]\ (m^3)$$

Since we set all of the units of water as cube meter in this paper, we divided the above formulation to 1000. Also, POP_t is amount of population in Tajan region in period t, that can be obtained as the following formula.

$$POP_t = POP_0 \times (1+ rate\ of\ growth\ in\ a\ month)^t \qquad \textbf{(3)}$$

At lost, municipal demand was calculated as:

$$Demand_t = Max\ \{\ POP_t \times 140 \div 1000 \times 30\ ,\ Q_{t-1} \cdot \left(1+E \cdot \frac{P_t - P_{t-1}}{P_{t-1}}\right)\}\quad \textbf{(4)}$$

In section 5, changes of municipal water demand in a specific period is compared when designed strategies will be applied.

- *Industrial Demand:*

  In horizon of our modeling (that is 24 months and starts from December 2010), it is recommended by experts that industrial equipment and production is nearly fixed. So, we could set the demand of industrial section a fix value, 2.8 Mm^3 per month.

2.2 Casual Loop Diagrams & Dynamic Hypothesis:

In this section, we depicted causal diagrams of different parts of model in order to develop flow model. The causal diagram of our model is consisted of three major sections that we introduced them here. These sections are agricultural and municipal demand and also supply subsystem.
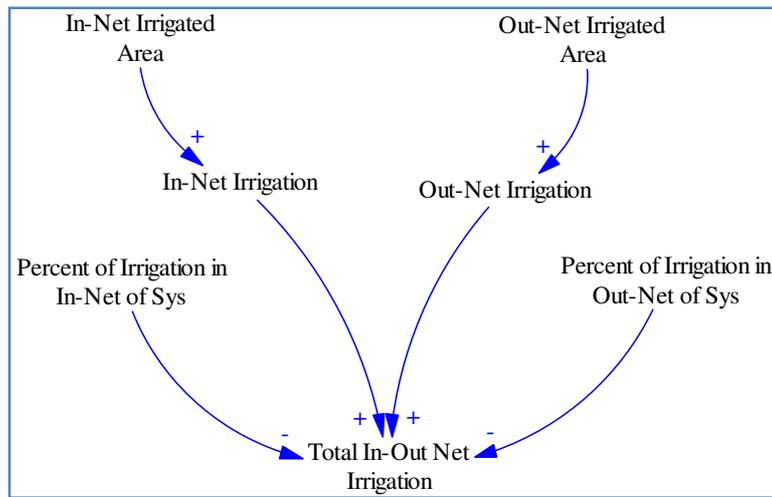

Figure4. Causal diagram of agricultural demand

As explained before, farms in Tajan were irrigated by two kinds of rivers supplies on the bases of their irrigation methods that were modern and classical. Total water needs for irrigating farms in Tajan are calculated by using this diagram. This amount is consisted of two parts as we mentioned before, in-net irrigation and out-net irrigation of farms during a year. In order to obtain each of these two parts, average distribution of agricultural demand which was shown in Table 2, should be multiply to areas of farms that are irrigated by in-net or out-net irrigation in a year. In Tajan, efficiency of the modern irrigation method is %41 while it is 33% for traditional. These values were used to obtain efficient amount of agricultural demand in the model. We considered them as percents affected two types of irrigation.
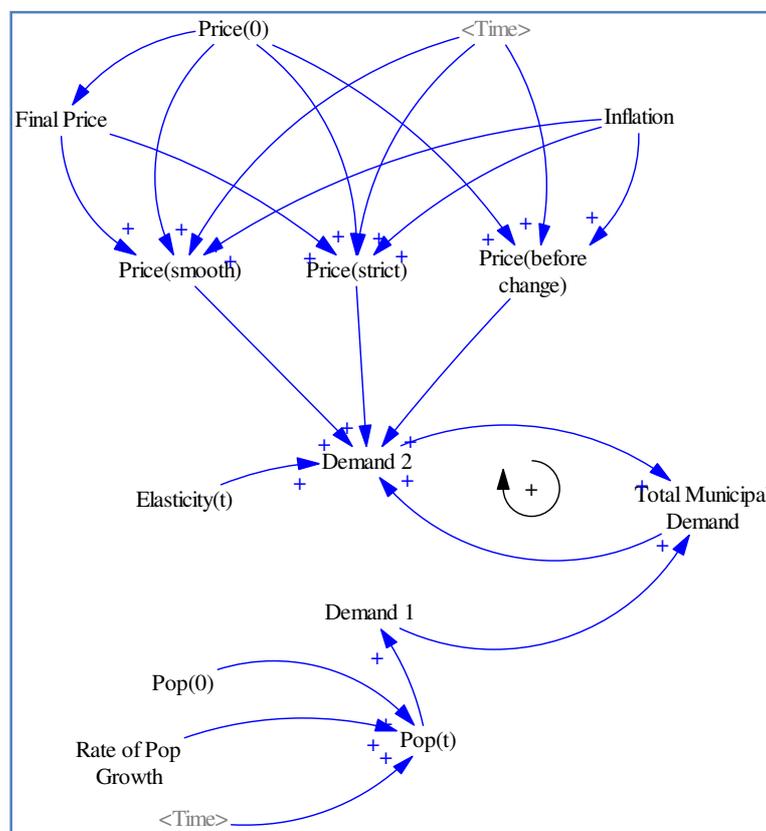

Figure 5. Causal diagram of municipal Demand

In Figure 4, causal diagram of municipal demand of water as the second and the main section of our demand subsystem is illustrated. By implementing cashing subsidy policy, water price increases. As we know, increasing of prices of goods or service lead to decreasing of their demand when other conditions are constant. But in the case of water, as we mentioned before, there is a minimum limit for consumption of water in municipal section.

So, we applied two kinds of demand in our model, Demand 1 and Demand 2. The first kind of demand is cumulative minimum needs of personal water per time unit for people. This

amount is depended to number of people which is time dependent too. We calculated this parameter by equation (3) and using existing data of Tajan population and its growth rate.

Demand 2 is calculated by equation (1). Elasticity of water in Tajan for each month was obtained by real data.

In this part of our model, we applied our strategies for implementing the policy. In fact, water price increases suddenly (strictly) or by a soft and smooth gradient. We used another strategy to compare these two strategies with each other. We calculated municipal demand when no cashing policy has been applied. It means water price is increased by its regular and monthly inflation which is 1% and was applied before 2010. Causal diagram of these three different strategies are shown in the top section of Figure 4.

According to the equation (2), it is obvious that total municipal demand is the maximum of these two kinds of demand. There is a positive loop between Demand 2 and total municipal demand that will be explained in the next section. Prices in each of three strategies are increased by rising of inflation and also passing time. Meanwhile, it is affected by initial price of water. Final price is considered to be the price of water without any subsidy. Its value has a vital effect on price in our first and second strategy.
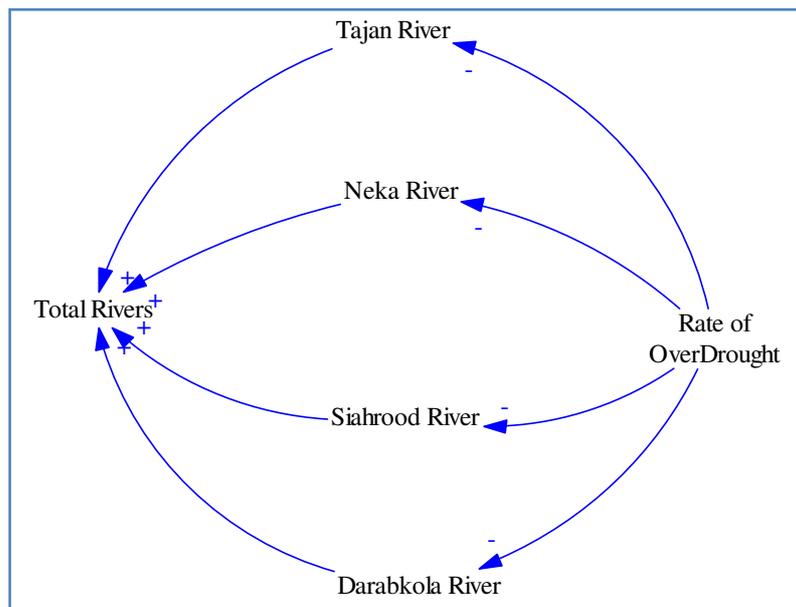
Figure 6. Causal diagram of supply subsystem

Total amounts of rivers are calculated by adding four rivers together according to Figure 5 in which causal diagram of supply is shown. We considered sudden climate changes in our model and called it "Rate of OverDrought" and set its value to be 5%. This variable had negative influences on the amount of rivers which was not a deniable matter. Since it is for years we have faced drought in Iran, a sensitive analysis can be done over this variable.

3. Model Development

   In this section, we developed our model and we tried to explain its characteristics. According to causal diagrams, the flow diagram is consisted of three parts. Left part is municipal demand where strategies are designed, right one is supply subsystem and top section is agricultural demand. The main variable of the model is "Surplus Supply Water" that is a criterion for comparing the effectiveness of the strategies and is calculated by subtracting total amount of rivers from agricultural, municipal and industrial demand of water.

   In the flow diagram, there are 5 stock variables. Four of them saved different amount of the four rivers and the other one save municipal demand. In this model, we were dealing with a discrete simulation since our time units were months and the modeling horizon was 24 months. So, we used those stock variables in order to entrap discrete amount of rivers and municipal demand. In fact, output flow for each of these stocks was exactly the input flow in its later period. It means we applied a delay between output and input flow. We must do it to avoid flows from accumulation. For example, the positive loop we were talking about in the previous section is consisted of total municipal demand and "Demand 2" and also municipal demand in its later period. We were obliged to apply this tricky idea since for calculating elasticity in equation (1), the amount of Q_{t-1} should be obtained first in order to obtain Q_t.

   In stock variables of rivers, out flow of a specific river is its inflow in later month by considering the influence of the rate of over drought in it.

   As you focus on the Vensim file of our model, we did not used look up function for giving average amount of rivers water according to Table 2. Since the rivers data is given per months, we did not have its value between each pair of continuous months. So, we used "IF Then Else" structure for inserting amounts of rivers into the model.

Figure 7. Flow diagram of model
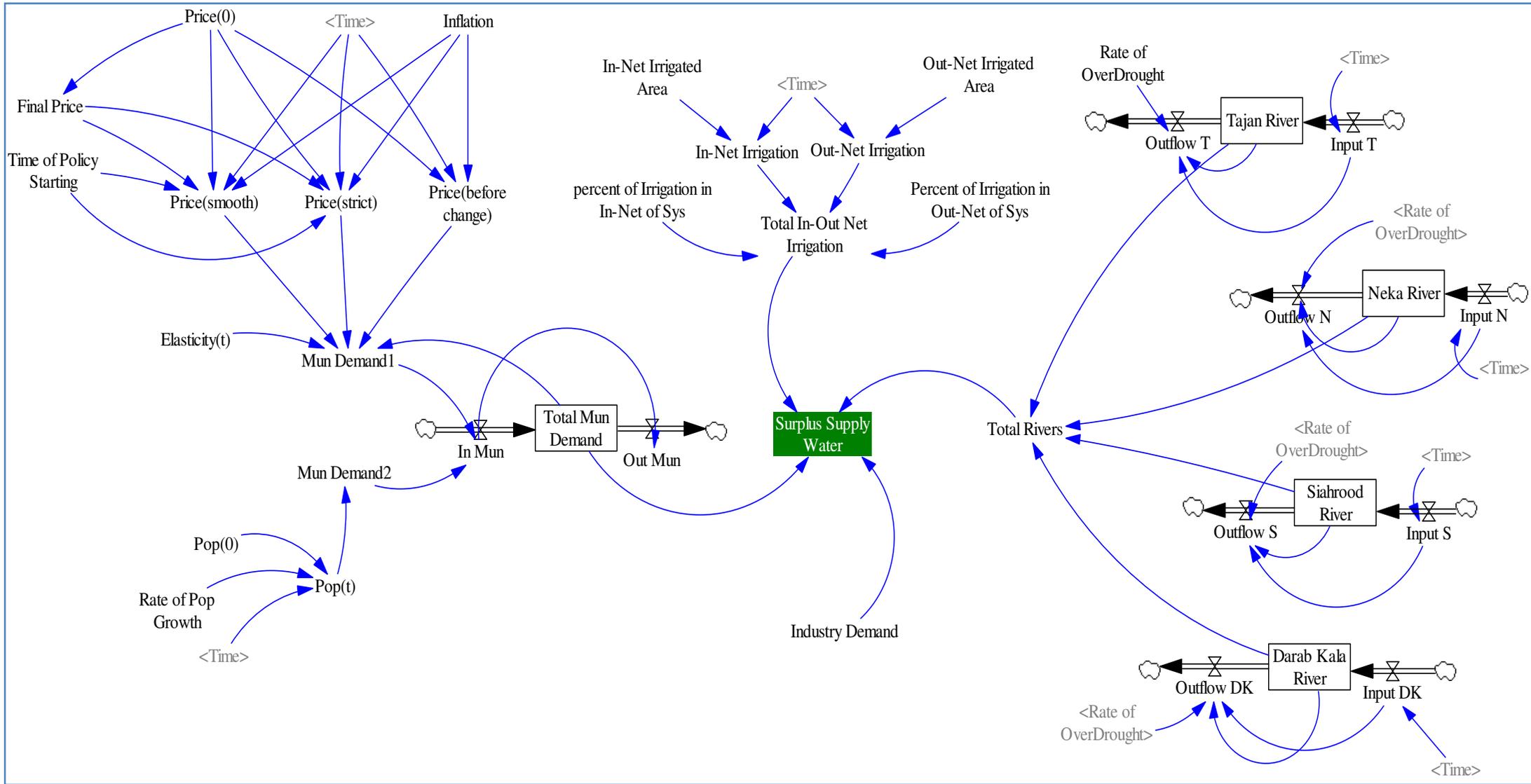
4. Simulation and Results

We used Vensime (Version 5.6b) for running our flow model. Water flows in each of the rivers is given to the model while the rate of over drought affects their flow. As Figure 8 shows, flows of Tajan River decrease in the second year with respect to the first year because it is multiply to the rate of drought. It is obvious that its maximum amount for the second year (month13) is a bit smaller than it value in the first month.
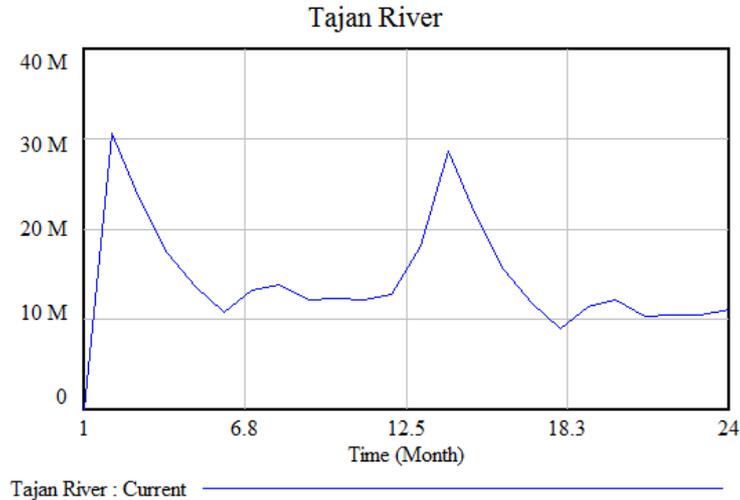

Figure 8. Flow diagram of Tajan River during the modeling horizon

As discussed before, three strategies for increasing water price were designed. In the first one, after starting of the cashing subsidy policy, water price rises a bit and after that it increases by small speed and in smooth gradient. Figure 9 illustrates this policy. It should be considered that unit of rivers flow is cubic meter per seconds.
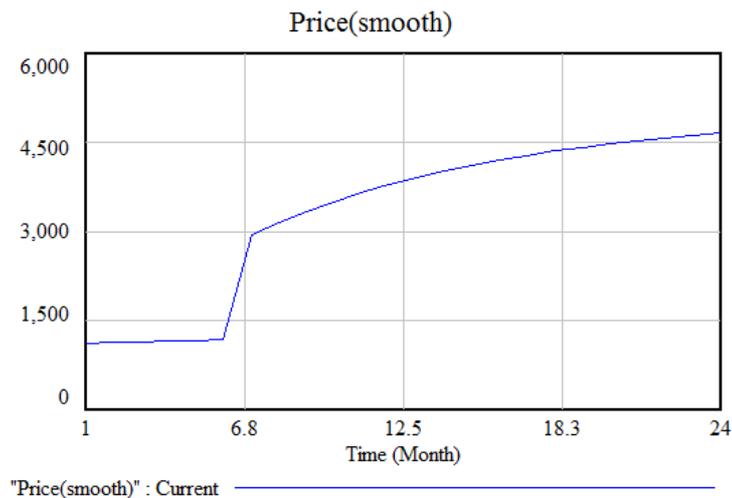

Figure 9. First strategy for water price, price increases smoothly

In the second strategy, water price increases strictly similar to what Iran's government started to do from December 2010. A big shocked happened in the prices. It can be seen in Figure 10.
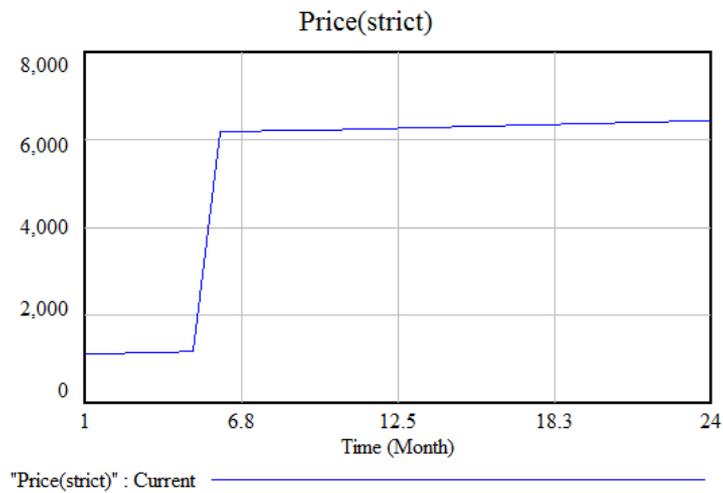

Figure 10. Second strategy for water price, price increases strictly

In order to find various effects of these two strategies, we have considered another strategy in which no cashing subsidy policy happened. Price of water increased according to the rate of inflation which was announced at the beginning of each year by the government. So, price rises linearly similar to Figure 11.
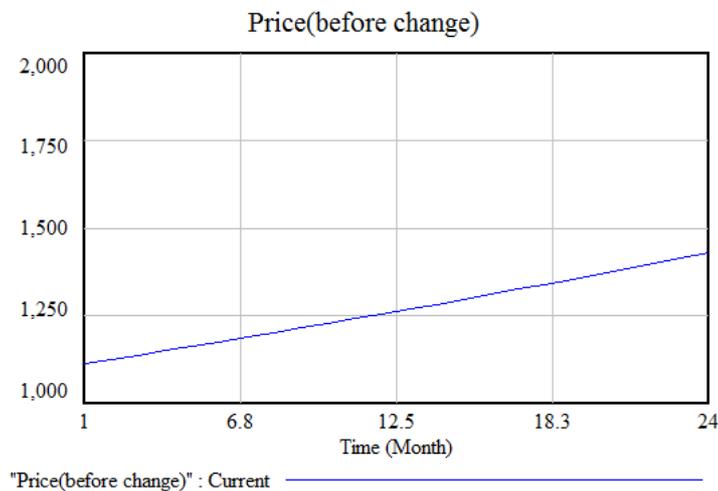

Figure 11. Third strategy for water price, price increases by inflation

In the following figures, diagram of the main variable is shown. In Figure 13 we focused on months between 7 and 12. As it is obvious, in these months it is a positive value. It should be notice the more surplus supply value, the better is the strategy.
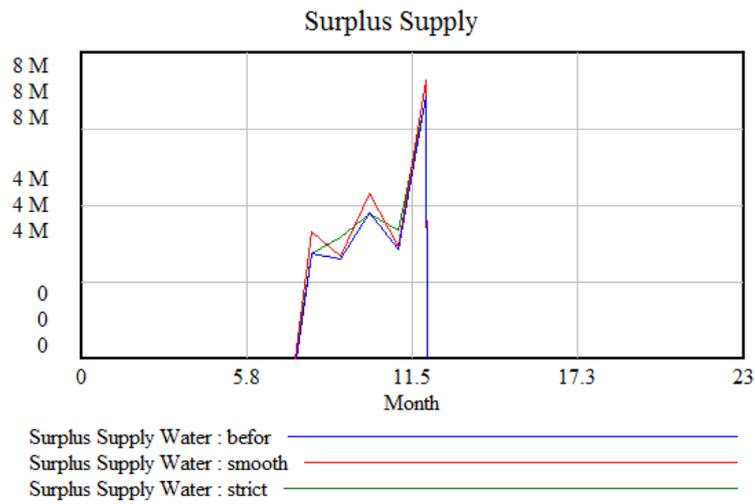
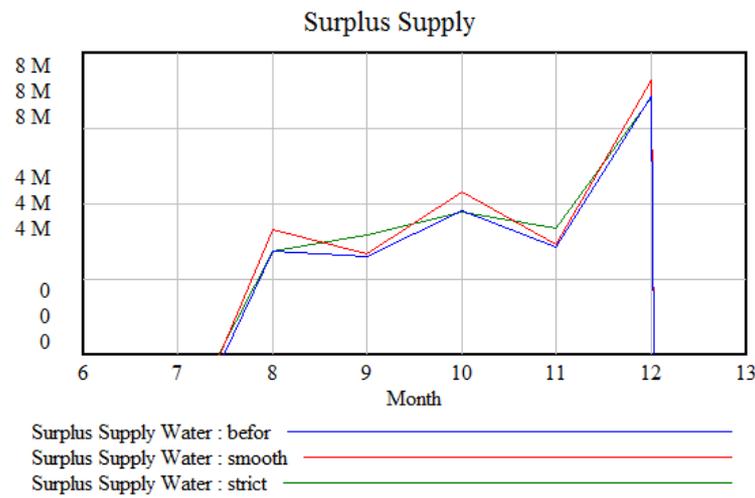Figure 12. Surplus supply for strategies during the modeling horizon

Figure 13. Surplus supply for strategies in a bold time periods

   Although in two months (month 9 and 11), the second strategy is the best one but integrated area under the red line that indicates smooth strategy is bigger than strict one. It can be inferred that the third strategy in which no cashing subsidy happened is the worst strategy since blue line is always under the other lines. Also it seems that second strategy is an average of the first and third.

5. Validity of Model

Surplus supply is a key variable in the model since it is affected by all of the other variables. Fluctuations of diagram in Figure 14, explain regular and normal changes in amount of water during 24 months. In months of September to March, surplus supply water increases to a positive value. It is the time of autumn and winter. Therefore, raining is a good supply for irrigation especially in north of Iran. Vice versa, in springs and summers, because of the lack of raining and severity of drought that lead to rising of water needs, this value goes down. So, other sources of water should be applied for agricultural activities such as shafts, dykes and return flow systems.

All in all, it seems we succeeded to model real environmental and economical behavior of Tajan system about cashing subsidy policy. By asking experts, it was also concluded that the value of surplus supply water is very close to its real quantity.
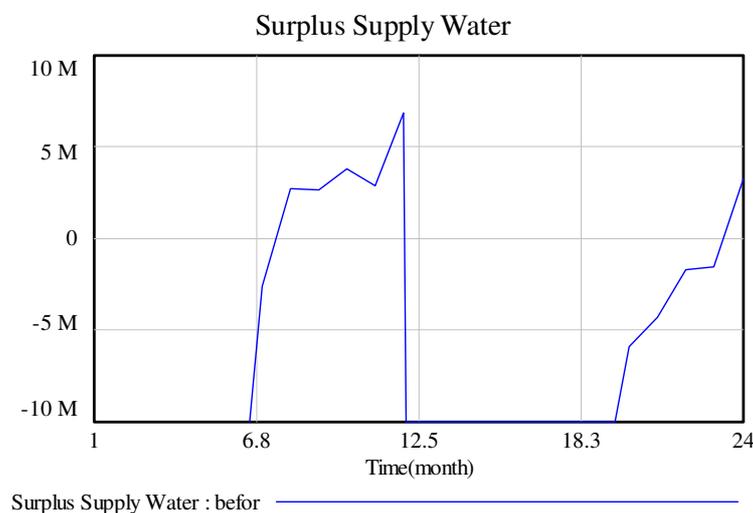
Figure 14. Surplus supply water and its changing in modeling horizon

6. Conclusion and Future Research

In this paper, we focused on the consequences of removing water subsidy in Tajan, an area in the north of Iran. Water supply and demand in Tajan were modeled by concepts of system dynamics. We explained the effects of cashing subsidies policy in municipal demand of water in Tajan as the main demand section that was affected by this policy. Three strategies were designed which were different approaches in implementing of the policy. In the first strategy, the price of water increased smoothly over modeling horizon which was considered to be 24 months. While in the second one, price was increased suddenly in the first month, exactly similar to the way Iran's government has done. A third strategy was designed to select the best one from the two strategies in which no subsidy elimination happens and the price increases according to inflation. A water surplus indicator was considered for comparing

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these strategies which was calculated by decreasing the amount of all of water supply resources from cumulative water in triple demand section for each strategy.

It is concluded that by increasing water price smoothly, the cumulative amount of positive surplus supply is bigger than the others. Although is two months strict strategy has a highest amount of surplus supply. So, despite of government decision in increasing the price strictly, it would be better to raise it slowly with a smooth gradient.

Also it was concluded that surplus supply water is very close to its real data. It means we succeeded to model the problem well and our model has a good validation.

For future researches, we suggest a sensitive analysis to be done for the key variables of the model such as over drought rate or inflation to discover the critical points. Different types of pricing strategy in a longer modeling horizon can also be considered to find the optimum one in a long time planning.

We assumed that the cashing policy has just changed municipal demand. It is recommended to find its influences on the other demand sections such as industry and agriculture in order to make an integrated model that can explain real conditions better.

7. Acknowledgment

8. References

- Ewers, M. E. (2005). Combining Hydrology and Economics in a Systems Dynamics Approach: Modeling Water Resources for the San Juan Basin. *The 23rd International Conference of the System Dynamics Society.* Boston.

- HO, C.-C., YANG, C.-C., CHANG, L.-C., & CHEN, T.-W. (2005). The application of system dynamics modeling to study impact of water resources planning and management in Taiwan. *The 23rd International Conference of the System Dynamics Society.* Boston.

- J., Sterman. (2000). *Business Dynamics: System Thinking and Modeling for a Complex.* Boston: McGraw-Hill Companies.

- Winz, I., & Brierley, G. (2007). The Use of System Dynamics Simulation in Integrated Water Resources Management. *The 50th International Conference of the System Dynamics Society.* Boston.

- Arbues, F., Barberan, R., and Villanua I., (2004). Price Impact on Urban Residential Water Demand: A Dynamic Panel Data Approach. *Water Resource Management, 4(1), 323-338.*

- Regional Water and Sewage Company of Mazandaran Provine. A Report of Social, Economical, Agricultural and Bestijal Studies: A Case Study of Tajan System. (2006). (in Farsi)

- Regional Water and Sewage Company of Mazandaran Provine, Ministery of Power. (2010).
  Retrieved from http://www.abfa-mazandaran.ir/89.mht (in Farsi)

- Naseri, H., & Zarei, B. (2007). *27th Geosciences and 13th Geological association.*
  Retrieved from http://www.ngdir.ir/Papers/PapersDetail.asp?PID=15640   (in Farsi)

- Sabouhi, M., & Nobakht, M., (2009). Estimating the Water Demand Function of Pardis City. *Journal of Water,* 10, 69-74. (in Farsi)

- Pajouhan, J., & Hosseini, Sh., (2003). Estimating Municipal Demand Function: A Case Study of Tehran, *Journal Economical Investigaation of Iran,* 16, 47-67. (in Farsi)

- *Tajan River.* (n.d.).
  Retrieved from National Geoscince Database of Iran (in Farsi)
   http://www.ngdir.ir/geoportalinfo/PSubjectInfoDetail.asp?PID=927&index=3