A Dynamic Model for Development Planning in an Arid Area

Mohammad T. Mojtahedzadeh
Institute for Research in Planning and Development
P. O. Box 19395/4647, Tehran, Iran

Abstract

Yazd is one of the regions in the central districts of Iran, entirely dependent on ground water for its water supplies. In such regions, as economy grows demand for water increases, but a serious economic crisis also appears due to depletion of ground water reserves. In this paper, a System Dynamics model is presented to analyze the interaction between socio-economic development and limited water resources. The model shows how the crisis would occur. The alternative policies is adopted to prevent such a crisis.

1-Statement of the Problem

Water is not only the lifeline of agriculture but, the factor of restriction in the progress of economic development in the central district of Iran, such as Yazd. Yazd, which has had a long history of water resources limitation, has been overdrafting its ground water supplies since the 1960s. The overdraft has grown tremendously, and during the last decade has averaged about 100 million cubic meters per year. Ground water pumpage has reached to 631 million cubic meters annually, while its recharge is about 459 million cubic meters. This recharge includes inflow of 275 million cubic meters rainfall, 184 million cubic meters restoration of consumed water, and 74 million cubic meters, inflow of water from other aquifers, per year. 93 percent of total pumpage is allocated for agricultural use (589 million cubic meters), 5 percent for drinking (29.8 million cubic meters), and 2 percent for industrial use (12.2 million cubic meters). As a result of continued ground water withdrawal far in excess of recharge, water level declined more than 25 meters, which accompanied with a decrease in ground water reserves about 4.5 billion cubic meters.

Population growth and imports restrictions on food under self sufficiency food policy, increase pressure to expand agriculture. As land under cultivation rises, if the performance of water irrigation remains unchanged, depletion of water reserves accelerate. Ground water extraction declines water level and increases water pumpage cost, if water pumping efficiency remains unchanged. Hence, incentive to develop agriculture reduces, so dose demand for water. During the last 3 decades, in Yazd, water irrigation methods have remained unchanged, while water pumpage efficiency has raised dramatically. As a result, pressures to run out water reserves have been accelerated.

Because of water resources limitation, industry should be considered as an important sector in the economy of Yazd. During the last decade, industrial activities have stagnated due to foreign exchange shortage. In the future, the rate of industrial progress depends on investment in large scale industries that produce intermediate and capital goods. such industries require water more than others. In Yazd, 97 percent of industries produce final goods with an old technology and just 23 percent of them are large.

Population on one hand, provides labor for economy, and on the other hand, claims the output of economic activities. Population is increased by net birth rate and is varied by migration. The migration depends on water quality and industrial activities. For Yazd which is in the primitive stages of economic development, is very important to keep skilled labour forces. During the period 1966-1976, population grew at an average rate of 2.5 percent per year, from 289 thousand to about 366 thousand people. This growth rate indicates that Yazd was emigrated, during the same period. Population increased to 582 thousand in year 1986. The rate of growth in period 1976-1986 was 4.66 percent per year, which indicates Yazd was immigrated during that period.

2-Conceptualization of the problem

Figure 1 shows the major feedback loops of dynamic model. These loops are useful to understand the nature of the problem, too.

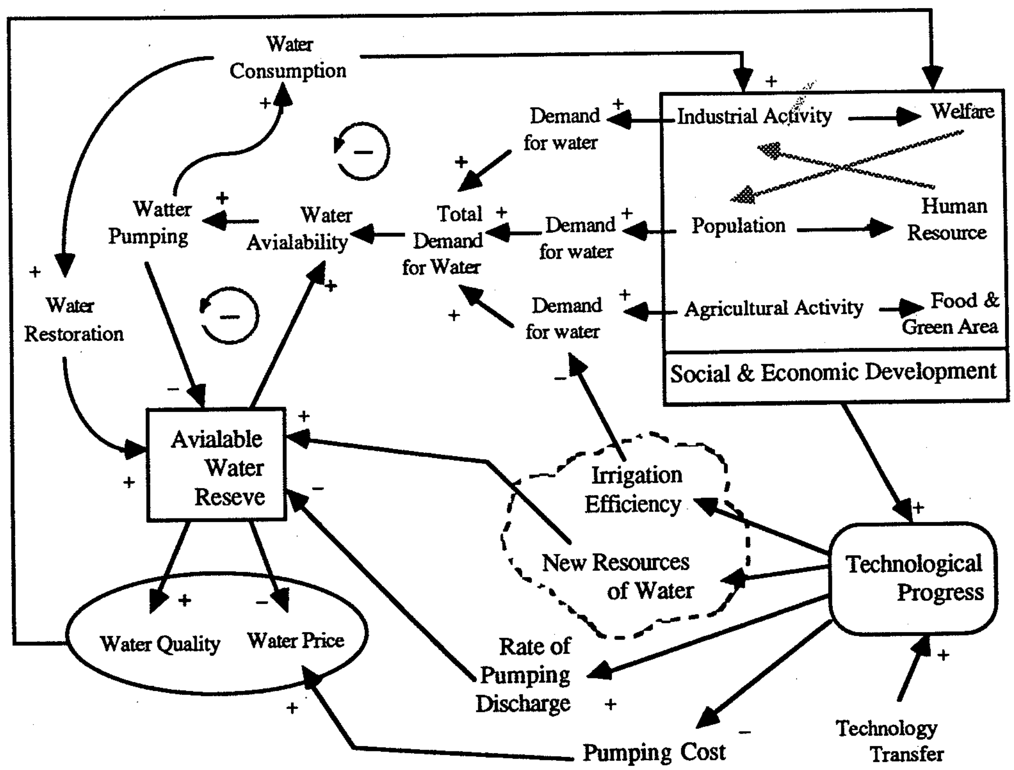


Figure 1: Major Feedback Loops of Dynamic Model

People carry out development. Industrial and agricultural activities are indexes of the level of development. As social and economic development occur, demand for water increases as well. Increasing in demand for water causes lower water availability. A low water availability restrict water extraction. Water extraction decreases available water reserves. Hence, demand for water cannot be met and economic activities would fall. Water availability is also affected by available ground water reserves. Available ground water reserves increase by a proportion of water consumption that returns to the aquifer. With decreasing in water reserves water

prices would rise and water quality would decline. Low water quality and high water price limit economic development.
Social & economic development stimulate technological progress. Technological progress may improve irrigation efficiency, discover new resource of water, decrease pumping cost and increase rate of pumping discharge. The effect of technological progress on pumping cost and rate of water discharge decreases water prices and leads to acceleration of agricultural activities. A higher irrigation efficiency causes lower demand for water. New resources of water would increase the available water reserves. In the past, technological progress has made a quicker water extraction possible along with a lower pumping cost. It gives Yazd a transitory opportunity for economic development, while ground water reserves is diminishing.

3-Model Construction

Figure 2 shows the overall structure of a System Dynamics model that considers important interactions for policy analysis in development planning in an arid area. The model consists of five sectors: Water, Industry, Population, Agriculture, and Urban Development. The interactions between these five sectors produce the dynamic behavior of the model.

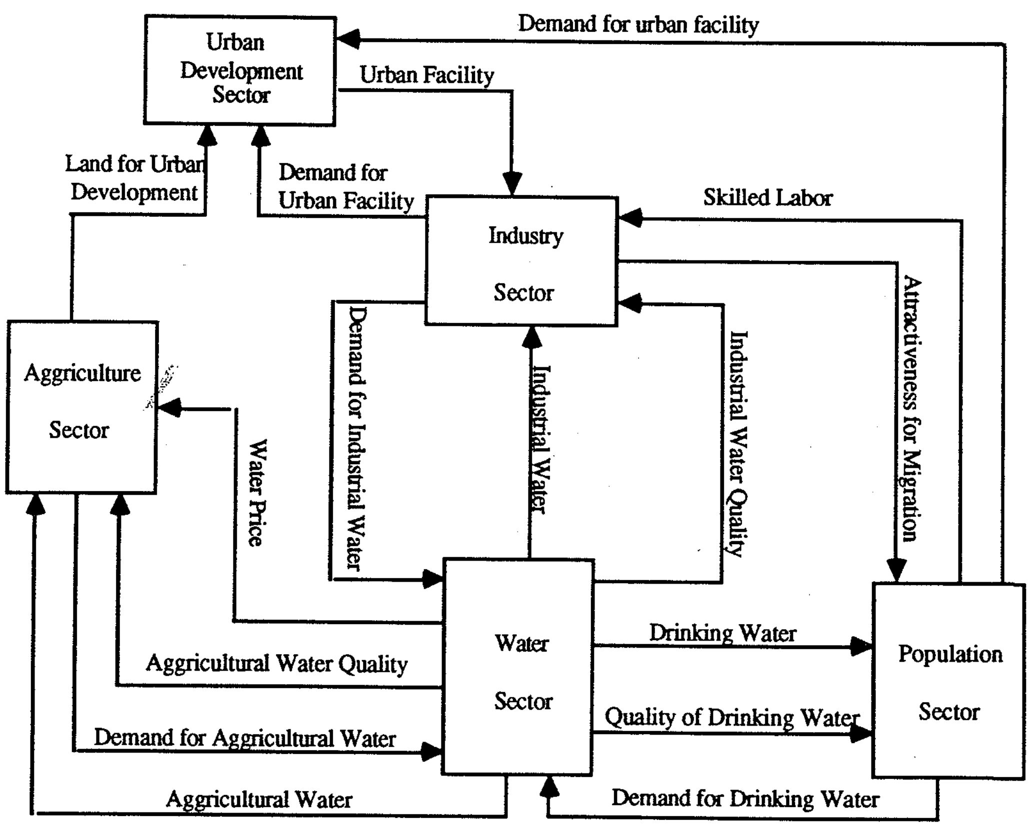


Figure 2 : Overal Structure of Dynamic Model

The water sector takes information about the demand for water from population, industry and agriculture sectors. Water sector determines total water consumption and water allocation between other sectors. This sector also provides information about water quality and water prices to population, industry and agriculture sectors. Water prices plays an important role in agricultural activities. Agriculture sector receives information about water prices and determines its demand for water. Population sector supplies labor force for economic development .This sector also provides information about demand for urban facilities to urban development sector. The latter sector provides such facilities based on information about demand for them received from population and industrial sectors.

4-The Base Run; How an Economic Crisis Might Occur

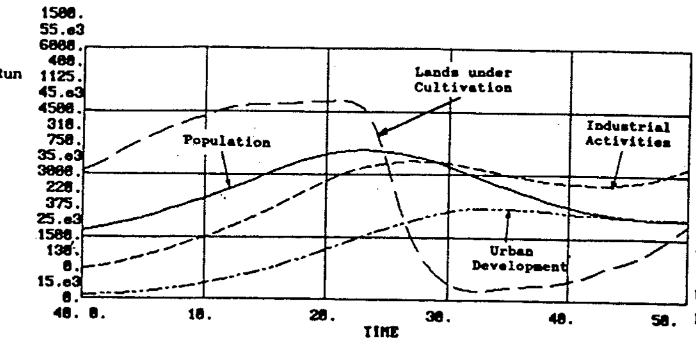
The behavior of all variables in figures 3a and 3b show a serious economic and social crisis that Yazd might face. Before year 20, population grows, land under cultivation increases, industrial activities develop and demand for water rises as well. The demand for water could only be met by investment in water sector to expand water pumping capacity. As water consumption grows, the gap between inflow and outflow of water increases and water reserves decline. Figure 3b shows that water reserves decrease before year 26 but increase because of a decrease in demand for water after this year. With decreasing in water reserves, water level in the aquifer would fall. In such a condition, aqueduct discharge would drop and more capital is needed to pump out a certain amount of water. Thus, marginal cost of water pumping would be more. Water prices is related to pumping cost and excess demand for water. Water price increases until year 27, because of dropping water level and rising excess demand. The government financial support would decrease the cost of the agricultural sector due to additional cost of water. After year 27, demand for water would decline due to deterioration of water quality and water prices would fall, while pumping cost is rising.

Decrease of ground water reserves has also a negative effect on water quality. With deterioration of water quality the trend of migration out of the region would be aggravated. From the year 25, the population of region will decline, and from 895 thousand, in year 25, will reach to 486 thousand in year 50. Industrial activities would halt due to skilled labor migration and more deterioration of water quality. The stagnation of industrial activities and decline in population would result the urban development to level after year 30. Agricultural activities rise until year 21, and, after this year, would fall sharply, because of decreasing of ground water supply. Land under cultivation grows until year 21 and from 35 thousand hectares will reach to 47 thousand hectares in year 21, and then, decrease to 17 thousand hectares in year 32 due to restricted water availability. It rises after year 32 and reach to 27 thousand hectares in year 50. Such an economic crisis would be disastrous.

5-Policy alternatives

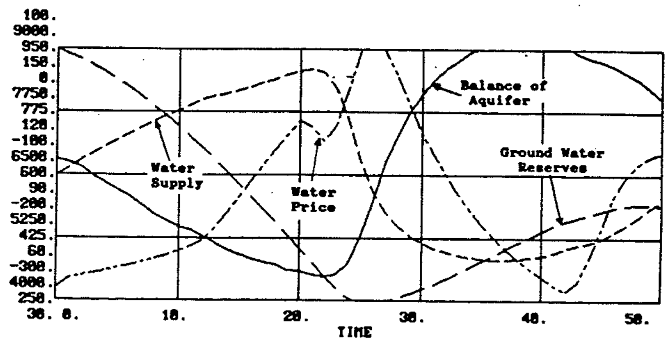
In order to prevent the crisis discussed in the previous section policies have to be adopted to improve the behavior of social and economic system of Yazd. The key to a successful policy is balancing the inflow with outflow of water in aquifer before exhaustion of ground water reserves. This section, examines alternatives policies and explains the new behavior by comparison to the model behavior in the base run.

Figure 3a
The Base Run



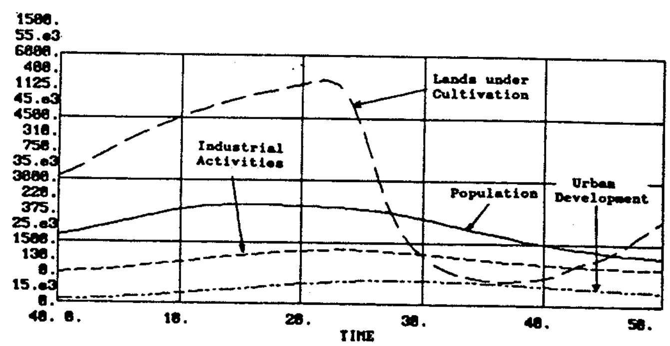
Population (thousand) (0,1500)
Lands under Cultivation (Hectares) (15e3,55e3)
Industrial Activities (0,6000)
Urban Development (0,400)

Figure 3b
The Base Run



Balance of Aquifer (Million M3) (-300,100)
Ground Water Reserves (Million M3) (4000,9000)
Water Supply (Million M3) (250,950)
Water Price (0,400)

Figure 4a
Restricting Population Growth & Industrial Development



Population (thousand) (0,1500)
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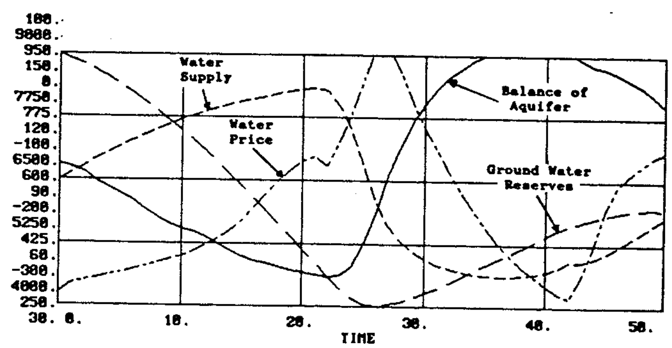
Figure 4b
Restricting Population Growth & Industrial Development



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5-1-Restricting Population Growth and Industrial Development

It might appear likely that limitation of population and industrial growth would eliminate the critical situation. Figure 4a and 4b show the dynamic behavior of the model under such a policy.

With restricting population and industrial growth, immigration decreases and would be about zero in year 15. The normal rate of annually growth in the industrial sector changes from 5 percent to 3.

The policy has not a considerable effect on system behavior comparing with the base run. because on one hand, the ratio of water demand in population and industry sectors to total demand is not too high, and on the other hand, the rate of industrial and fresh water restoration into aquifer is more than its rate in the agriculture sector. Under this circumstance, restricting water demand in population and industry sectors, not only do not solve the crisis problem but, leads to less developed industry sector in the future. In year 50, the level of industrial activities would be less than half of its amount in the base run. Population would reach to 300 thousand, which is less than 40 percent of its amount in the base run. Land under cultivation grows just a little more than it does in the base run. The net result is that the crisis problem is aggravated.

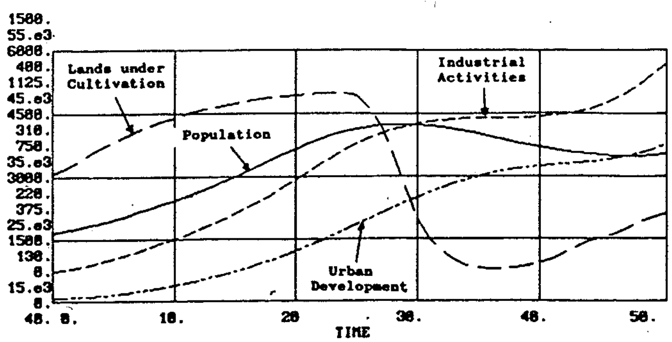
5-2-Water Transfer from other areas

Water transfer from other areas satisfies a portion of water demand. Furthermore, restoration of transferred water into aquifer causes an increase in ground water reserves. The project of water transfer starts at year 0, and will take 10 years to be completed. In the year 10, 80 million cubic meters water is transferred from other areas. The transferred water is allocated for urban and industrial use. Water transfer causes underutilization of ground water pumping capacity. It releases the pressure of economic activities on ground water reserves. Agriculture sector would not permit such equipment of water pumping to remain idle and try to utilize them, gradually. Figure 5a and 5b show the response of the model to water transfer. The policy satisfies a major part of water demand in urban and industrial sectors, and protects them against water quality deterioration. Industrial activities do not stagnate as they do in figure 3a. In the year 50, the level of such activities would be 7.5 times more than its quantity in the base run. Industrial progress would have a positive effect on immigration, hence, would result a more rapid rate of population growth. Until year 25, rapid growth land under cultivation, put development pressure on groundwater reserves. Water transfer requires construction of many facilities. Therefore, water prices, in this run, rise above that of the previous run, during most of the simulation time.

5-3-Restricting Agricultural Progress

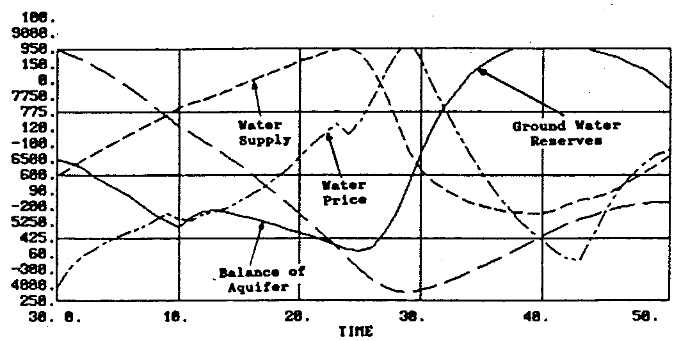
Water transfer though important would not enable the region to release the pressure of agricultural activities on ground water reserves. In order to eliminate such pressure, water consumption in agricultural sector should be adjusted, before falling due to depletion of ground water reserves. As water reserves decrease, ground water level falls and more capital is needed to pump out a certain amount of water. Hence, average cost of pumping would rise. This average cost accompanied with effect of excess demand for water, determine water prices. If government do not support the agricultural activities, and technology of pumping remains constant, an increase in water prices restricts agricultural activities. As shown in figure 6a and 6b, restricting agricultural progress, and water transfer, improve the behavior of model

Figure 5a
Water Transfer from other Areas



Population (thousand) (0,1500)
Lands under Cultivation (Hectares) (15e3,55e3)
Industrial Activities (0,6000)
Urban Development (0,400)

Figure 5b
Water Transfer from other Areas



Balance of Aquifer (Million M3) (-300,100)
Ground Water Reserves (Million M3) (4000,9000)
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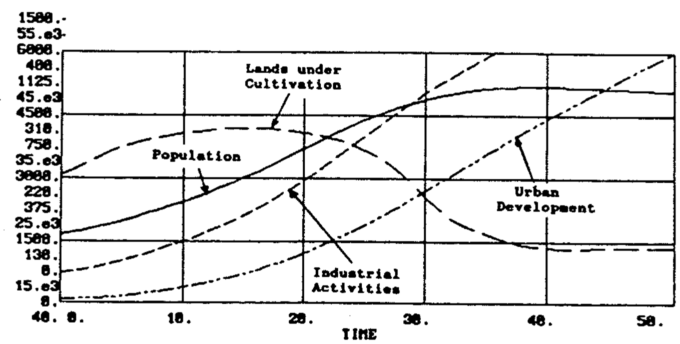
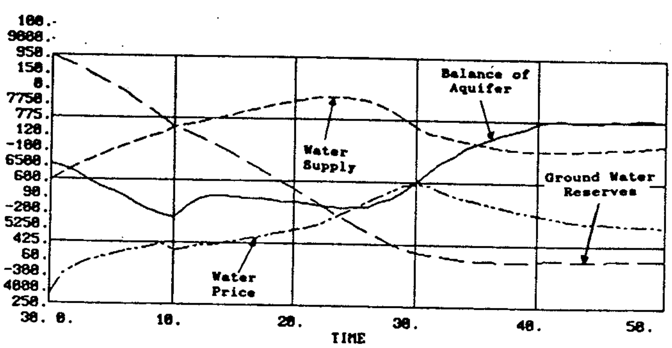
Figure 6a
Restricting Agricultural Progress



Population (thousand) (0,1500)
Lands under Cultivation (Hectares) (15e3,55e3)
Industrial Activities (0,6000)
Urban Development (0,400)

Figure 6b
Restricting Agricultural Progress



Balance of Aquifer (Million M3) (-300,100)
Ground Water Reserves (Million M3) (4000,9000)
Water Supply (Million M3) (250,950)
Water Price (0,400)

and system would be more stable. Relative to the last run, industrial activities are higher during the simulation period. Land under cultivation although, grow with a lower rate, but would be more stable.

5-4-Improvement of Water Irrigation Methods

The level of agricultural activities, in the future, depends on water irrigation efficiency. With improving in water irrigation efficiency, land under cultivation grow, without additional water consumption. Water for irrigating a hectare of land, per year, is declined smoothly, and from 15280 cubic meters in year 10 would reach to 13960 cubic meters, in year 50. Such improvement reached by a more rapid rate of increase in capital equipment for cultivation. Figures 7a and 7b, show the behavior of the model, when three policies; water transfer, restricting agricultural activities, and improvement of water irrigation methods are adopted. Under such policies, lands under cultivation rise above that of the previous run. Industrial activities develop with a higher growth rate. Population and urban development are slightly higher than what they are in the last run. Ground water reserves do not decline as much as in the previous run.

5-5-Avoiding the Transfer of Water

It might appear, that limitation on agricultural activities and improvement of water irrigation methods can eliminate the crisis and water transfer from other areas could be avoided. Figures 8a and 8b show the model behavior under such policies. As can be seen in the figures, the instability of the system re-aggravate. Industrial activities, population and urban development all have lower values in this run, relative to the last run.

6-Conclusion

In this paper, a System Dynamics model is developed to analyze the interaction between socio-economic development and finite water resource in the arid areas. The dynamic model is divided into five sectors: Water, Agriculture, Industry, Population and Urban Facility.
The model shows how the possible crisis would occur during the process of economic development in an arid area. In order to prevent the crisis, different policies such as water Transfer from other areas, Omission of government financial support for the agriculture sector and improvement of water irrigation methods are examined in the model. The model demonstrates that non of the policies alone could prevent the crisis. However a combination of them could resolve the problem and save the region from a sever crisis which would occur otherwise.

Acknowledgement

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Figure 7a
Improvement
of water
Irrigation
Methods

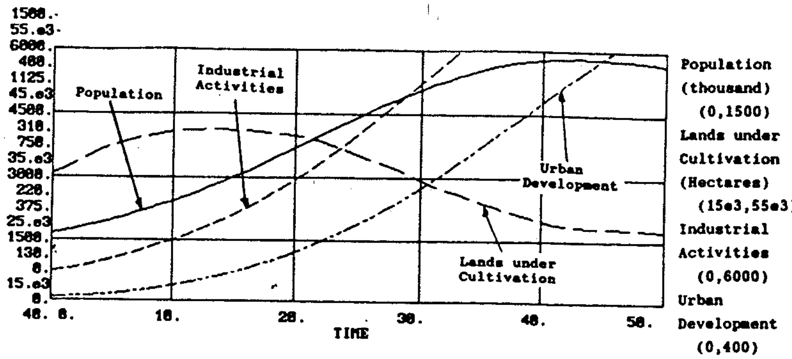


Figure 7b
Improvement
of water
Irrigation
Methods

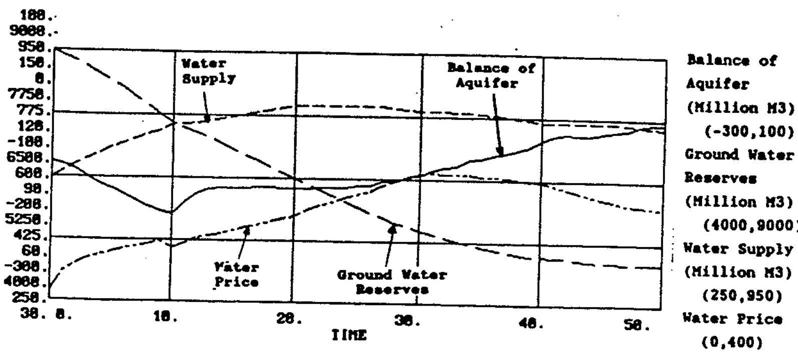


Figure 8a
Avoiding
the Transfer
of Water

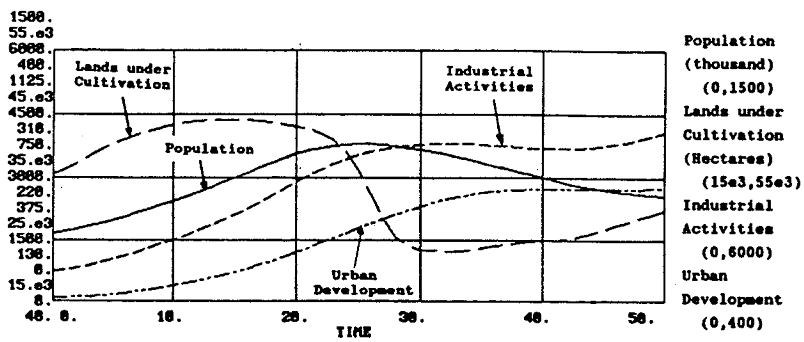
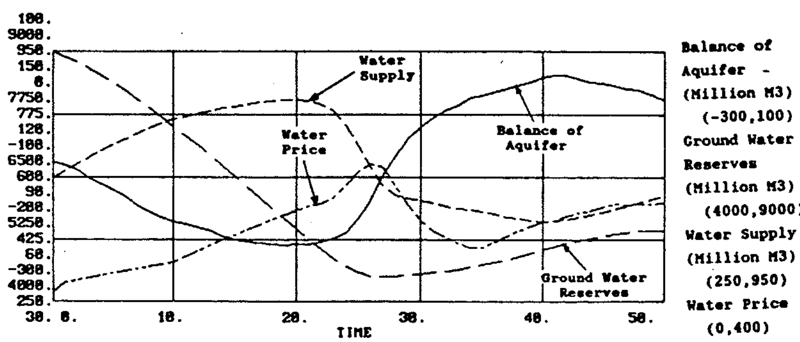


Figure 8b
Avoiding
the Transfer
of Water



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