DYNAMIC MODELING FOR REHABILITATION OF IRRIGATION NETWORKS (CASE STUDY: QAZVIN IRRIGATION NETWORK)

MODELISATION DYNAMIQUE POUR LA REHABILITATION DES RESEAUX D'IRRIGATION (ETUDE DE CAS : RESEAU D'IRRIGATION QAZVIN)

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ABSTRACT

Irrigation networks often are seen to perform below the expectation level, requiring their rehabilitation. Unfortunately, rehabilitation works are taken up on a piece-meal basis. Involvement of many time-dependent components in irrigation rehabilitation and their interactive complex relations on the system performance requires a system dynamics approach. Use of system dynamics modeling enables one to evaluate several rehabilitation scenarios and their effects on the network performance. In this paper, such an approach is presented for modeling rehabilitation of irrigation networks. The long-term influences of rehabilitation scenarios on system utility will be determined and the appropriate policies could be suggested.

The proposed approach has been applied on Qazvin Irrigation Network. Three scenarios for network rehabilitation are considered as: fixing the area under cultivation, decreasing groundwater extraction and increasing investment in renovation projects. The model is constructed in Vensim environment. For rehabilitation of irrigation networks, main elements that affect the networks utility are considered as efficiency, adequacy, equity, flexibility and stability in water delivery. The efficiency of the system under different scenarios is calculated and the final effects on the system utility are determined. Results show that all of these three scenarios improved the system utility; however "fixing the area under cultivation" scenario showed a better improvement. In conclusion, it could be stated that system dynamics approach is an efficient and useful method to tackle the complex problem of irrigation network rehabilitation.

Key words: *Irrigation network, System dynamics, Network rehabilitation, Alternative scenarios, System efficiency.*

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RESUME

L’évaluation des réseaux d’irrigation montre que leur utilité est inférieure à ce qui est prévu en raison d’une mauvaise conception et le fonctionnement, le manque d’entretien suffisant et une mauvaise gestion. La mauvaise performance des réseaux d’irrigation est en partie en raison de leur âge, ce qui nécessite une rééducation. Réhabilitation des systèmes d’irrigation sont pratiqués sur la base qui manque d’intégration et une approche systémique et qu’elle n’a pas conduit à une amélioration considérable. Participation d’un si grand nombre de composants dépendant du temps dans la réhabilitation d’irrigation et de leurs relations complexité interactive sur les performances du système qui sont dépendantes du temps nécessite une approche dynamique du système. Il est nécessaire d’appliquer des techniques de simulation qui représentent des systèmes dynamiques complexes d’une manière réaliste. La dynamique des systèmes, une approche de simulation basé sur le feedback orienté objet, est présenté pour la réhabilitation de modélisation des réseaux d’irrigation. La facilité de modification du modèle en réponse aux changements dans le système et la capacité d’effectuer une analyse de sensibilité que cette approche intéressante pour la modélisation de réhabilitation des réseaux d’irrigation. Utilisation de la dynamique du système de modélisation, plusieurs scénarios de réhabilitation pourraient être examinées et leur effet sur les éléments de performance (efficacité, l’adéquation, l’équité, la souplesse et la stabilité) pourraient être étudiés. Les impacts à long terme des scénarios de réhabilitation sur l’utilité du système sera déterminée et les politiques appropriées pourraient être suggérées.

Dans cet article, l’approche proposée est appliquée sur la réhabilitation des réseaux d’irrigation. Modèle conceptuel pour la réhabilitation des réseaux d’irrigation est élaboré en tenant compte des archétypes et des paramètres fondamentaux qui influent sur l’utilité du système et des boucles causales pertinentes. Le modèle dynamique du système est construit dans un environnement Vensim. Pour la réhabilitation des réseaux d’irrigation, les principaux éléments qui influent sur l’utilité des réseaux sont considérés comme l’efficacité, l’adéquation, l’équité, la souplesse et la stabilité dans l’approvisionnement en eau. Le modèle est appliqué sur le réseau d’irrigation Qazvin, trois scénarios pour la réhabilitation du réseau sont considérés comme: - la fixation de la superficie cultivée, qui empêchent tendance à la hausse du développement agricole et activer renforcement boucle dans Fixe qui ne Archetype avec l’augmentation de rendre la consommation d’eau, 2 - diminuer le retrait d’eau souterraine moins que le retrait admissible qui active boucle de régulation dans les limites de la croissance Archetype avec le contrôle de la demande en eau et prévenir tendance à la hausse du retrait des eaux souterraines; 3 - et de l’investissement dans la rénovation qui active boucle de régulation dans les correctifs qui ne Archetype avec la diminution de la physique les pertes et de gestion. L’effet des scénarios sur l’efficacité du système est calculé et l’impact final sur l’utilité du système sont déterminés. Les résultats montrent que l’ensemble de ces trois scénarios amélioré l’utilité du système mais “la fixation de la superficie cultivée” scénario a montré une meilleure amélioration. En conclusion, on peut dire que la dynamique du système approche est une méthode efficace et utile pour s’attaquer au problème complexe de la réhabilitation du réseau d’irrigation.

Mots clés : *Réseau d’irrigation, dynamiques du système, réhabilitation du réseau, scénarios alternés, efficience du système.*

(Traduction française telle que fournie par les auteurs)

1. INTRODUCTION

A major part of the 250 million ha of irrigated lands worldwide is served by surface canal systems. There is a critical need for improvement in: the service to irrigated agriculture and the cost-effectiveness of infrastructure management (Renault, 2007). In Iran, assessment of irrigation networks shows that their utility is unsatisfactory, because of poor design and operation, lack of sufficient maintenance, and mismanagement (Monem et al., 2000). Irrigation networks are expected to improve irrigation efficiency; but their efficiency is 30 to 35 per cent in Iran, due to insufficient operation and maintenance (Siahi, 2007).

Rehabilitation is a process of improving resources (labor, water, economic and/or environmental) utilization by upgrading the hardware and software in irrigation projects with maintaining or improving the water delivery service to farms (FAO, 2002). Irrigation rehabilitation is often misunderstood as exclusively resorting to physical changes and automation, while the integrated role of hardware and software rehabilitation is not considered properly. “Modern irrigation management is essentially concerned with responding to the needs of current users with the best use of the available resources and technologies as well as a sense of anticipating the future needs of the scheme” (FAO, 2007). The major aspects of irrigation networks rehabilitation addressed in researches after 50s are shown in Table 1:

Table 1 – Major aspects of irrigation networks rehabilitation after 1950s (Vaez Tehrani & Monem, 2008)

	Aspects	Results
1950s - 1980s	Technical solutions and improving engineering design of irrigation networks	Conventional engineering solutions failed to solve the problem of irrigation performance
1980s	Paradigm shift towards improving networks management considering social, economicl, political and legal aspects	Management practices may not alone result in substantially improved irrigation performance
1990s	New approach to irrigation design and management concurrently, Modern water control in irrigation, supply water on demand	Continued unsatisfactory performance of irrigation projects: Introduction of the new approach of network rehabilitation but unaware on its application.
FAO(2002)	Impact of irrigation management transfer on the performance of irrigation projects	In irrigation networks rearranging the “deck chairs” is unlikely to achieve significant improvements in irrigated agricultural productivity
FAO(2007)	MaSSCOT approach for canal operation improvement from the diagnosis up to the formulation of operational units and planning of a service objective agreed upon by the users	Assessment of systems status-quo but implementation without feedback analysis did not improve irrigation performance as expected

The Qazvin development plan consists of series of projects which has been carried out through 3 decades. Water supply activities from surface water (Taleghan and other local rivers) and ground water resources, water conveyance and distribution down to farm outlets were the major tasks of Qazvin Irrigation Plan. In the present paper, Qazvin Irrigation Network has been chosen as a case study because of low efficiency in distribution and conveyance canals, losses, longitudinal cracks in canals, damage of lining, weed growth, sedimentation and poor operation and maintenance and finally poor performance of network. For example, as shown in figure 1, the application, distribution and conveyance, and overall efficiency factors of Qazvin Irrigation Network in Iran from 1991 to 2006 are decreasing and that is an important issue to be considered in rehabilitation of the irrigation network.

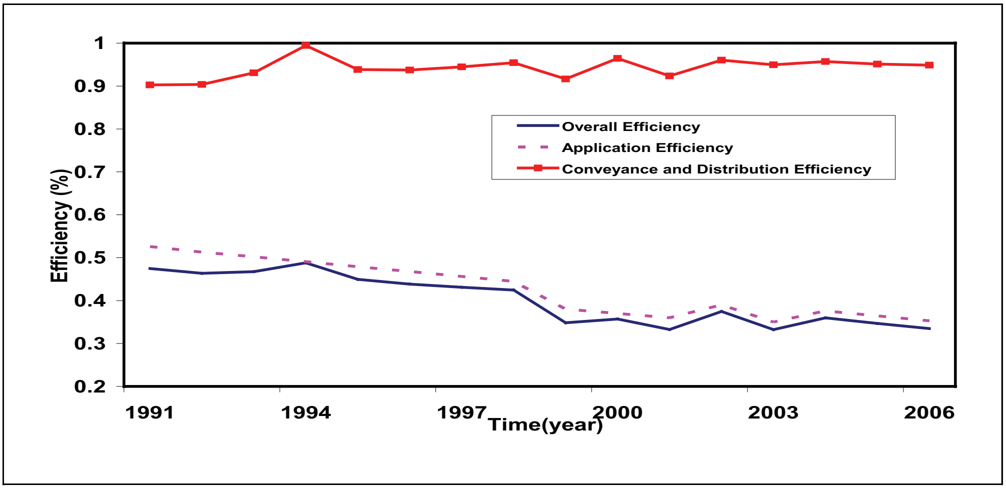


Fig. 1. Various efficiencies of Qazvin Irrigation Network (Siahi, 2007)

The present study aims to answer the following question:

1. What are the reasons for poor performance of irrigation networks?

2. How system dynamics may help in irrigation network rehabilitation?

3. How can the management be advised to improve network utility?

2. METHODOLOGY

2.1 The system dynamics approach

In this approach, systems are closed (Fig. 2), contrary to the open systems (Fig. 3), with feedbacks from outputs to inputs and taking care of interactions among the elements (Bagheri 2006; Hjörth and Bagheri 2006). It is a useful tool to study the trends of changes and their causes, to understand the physical processes and the flow of information, and to design and simulate the consequences of policies in a system. The interactions of system elements make its “structure” which is responsible for the system behavior (Sterman 2000; Vlachos et al. 2007).

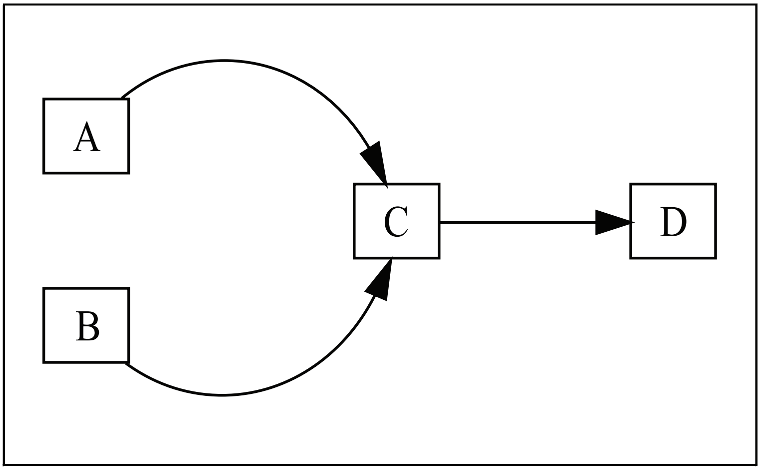


Fig. 2. Open systems according to linear thinking

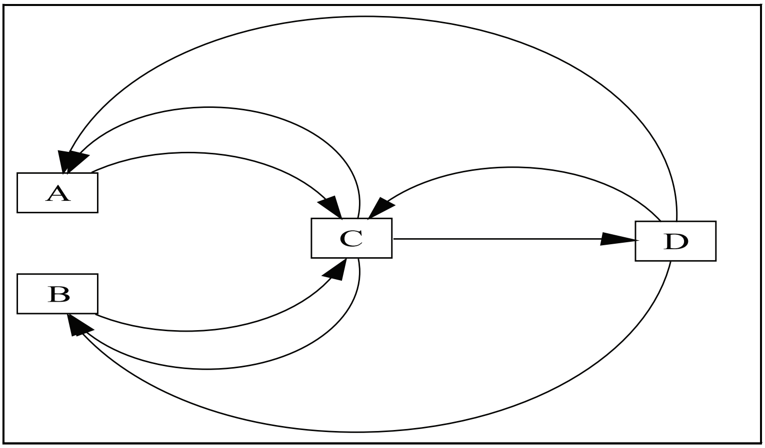


Fig. 3. Closed systems according to systems thinking

The stages of modeling in system dynamics are: Problem definition; System description; Model development and verification; Policy design and simulation (Stave 2003).

2.2 Rehabilitation of irrigation networks

Rehabilitation is a process enabling improvement in resources use efficiency. The overriding principle of modern irrigation is that irrigation is a service to farmers which should be as convenient and efficient (FAO, 2002). In rehabilitation of irrigation networks, main indicators that affect the Networks Utility are efficiency, adequacy, equity and stability in water delivery (Mohseni Movahed & Monem, 2002). In this paper, for investigation of utility, above indicators as well as an indicator on flexibility was considered.

2.3 Qazvin Irrigation Network

The Qazvin Irrigation Plan is shown in Figure 4.

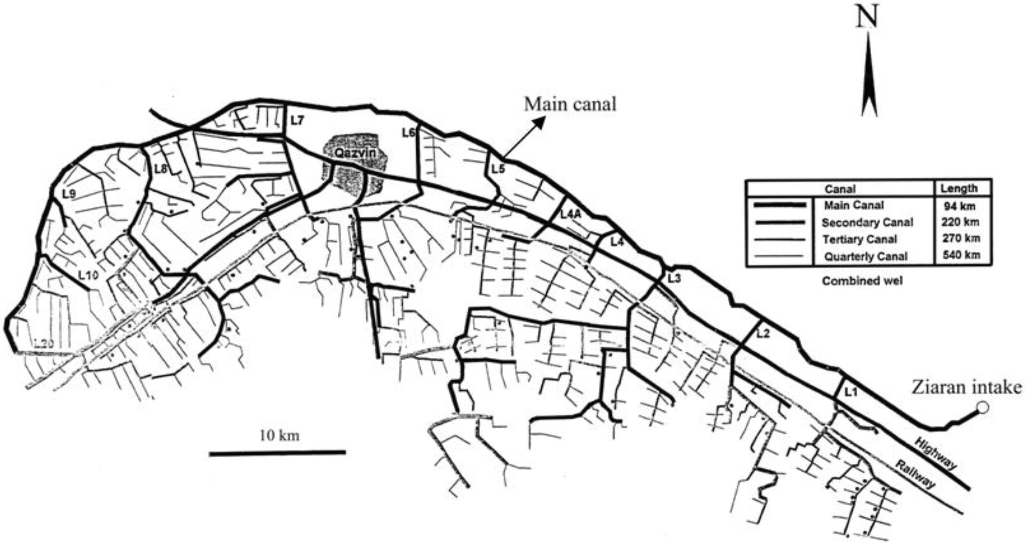


Fig. 4. Qazvin Irrigation Network

The prevailing circumstances of operation of the Qazvin Irrigation Network are: 1- constraints in water supply from Taleghan River, 2- decline in groundwater table especially in the western areas and rising water table in some other areas, 3- postponing the plan of groundwater recharge, 4- low water application efficiency, crop pattern alteration and increase of crop water demand, 5- deterioration of the canals concrete lining, 6- discord in conjunctive water use, 7- mismatch between water supply and demand, 8- poor overall efficiency (Siahi, 2007). In this research, a part of the model was run for Qazvin Irrigation Network and the effects of current situation and applying rehabilitation policies compared. The factors which are chosen as basis of policy making are: a) increasing of crop water demand because of efficiency decreasing from 55% in expected plan to 35% at present (Fig. 1), b) increasing of groundwater withdrawal and continuing groundwater table decline, especially in the western areas, c) increasing of cultivated area from 52000 ha to approximately 59000 ha, and d) increasing of the canals concrete lining deterioration because of poor operation, lack of sufficient maintenance and weakness of management (Siahi, 2007).

2.4 Applied equations

The System Utility is calculated using the following steps:
1) Calculate volume of water delivery to irrigation network (V_c) by:

$$V_c = V_{Surf} + V_{Draw} + V_{Well} \tag{1}$$

where V_{Surf} is volume of surface water (from Toleghan and Ziaran Dam); V_{Draw} is groundwater withdrawal volume and V_{Well} is water volume from combined wells.

2) Calculate water loss volume (V_L), corrected water loss volume (V_{Lc}) and conveyance - distribution efficiency ($e_{c\text{-}d}$) by:

$$V_L = V_c - V_{\mathrm{Re}ch} - V_f \tag{2}$$

$$V_{Lc} = \frac{V_L}{Op} \tag{3}$$

$$e_{c-d} = \frac{V_{Lc}}{V_c} \tag{4}$$

where V_{Rech} is artificial recharge volume; V_f is volume of water delivery to field and Op is investment in renovation plans execution.

Note: definition of efficiencies will mention in number 5.

3) Calculate investment in renovation plans execution (Op) by:

$$Op = Mo \times C_{erod} \tag{5}$$

where Mo is renovation plans execution and C_{erod} is annual network erosion coefficient.

4) Calculate renovation plans execution (Mo) by:

$$Mo = \frac{(P_{main} + P_{dredg})}{Utility} \tag{6}$$

where P_{main} is operation and maintenance costs; P_{dredge} is dredging costs (in present paper costs defined as percentage of incomes).

5) Usual efficiencies in irrigation networks are conveyance, distribution and application efficiencies defined as: $e_p = e_c \times e_d \times e_f$, where e_p is total efficiency, e_c, e_d, e_f are conveyance, distribution and application efficiencies respectively.

$$e_c = \frac{V_d}{V_c} \qquad e_d = \frac{V_f}{V_d} \qquad e_a = \frac{V_a}{V_f} \tag{7}$$

where V_d is volume of water delivered to distribution system, V_c is volume of water delivered to conveyance systems, V_f is volume of water delivered to field and V_a is crop water use.

6) From the viewpoint of network manager and considering to efficiency index system utility is function of system efficiencies and operation adequacy. In addition to usual efficiencies, operation efficiencies are product of delivery and withdrawal efficiencies defined

as: $e_{op} = e_{dr} \times e_{de}$ where withdrawal groundwater efficiency (e_{dr}) is excessive volume of withdrawal from groundwater related to allowable withdrawal:

$$e_{dr} = \begin{cases} \dfrac{V_{Allow}}{V_{Draw}} & V_{Allow} < V_{Draw} \\ 1 & V_{Allow} = V_{Draw} \end{cases} \tag{8}$$

where V_{Allow} is allowable withdrawal and V_{Draw} is real withdrawal volume from aquifer. And delivery efficiency (e_{de}) is excessive volume of water delivered to field related to required water:

$$e_{de} = \begin{cases} \dfrac{V_{\mathrm{Re}\,q}}{V_f} & V_{\mathrm{Re}\,q} < V_f \\ 1 & V_{\mathrm{Re}\,q} = V_f \end{cases} \tag{9}$$

where V_{Req} is required volume of water (water demand).

7) Calculate operation adequacy (A_{op}) defined as: $A_{op} = A_{dr} \times A_{de}$ where withdrawal groundwater adequacy (A_{dr}) is real volume of groundwater withdrawal related to allowable withdrawal:

$$A_{dr} = \begin{cases} \dfrac{V_{Draw}}{V_{Allow}} & V_{Draw} < V_{Allow} \\ 1 & V_{Draw} = V_{Allow} \end{cases} \tag{10}$$

And delivery adequacy (A_{de}) is volume of water delivered to field related to required water:

$$A_{de} = \begin{cases} \dfrac{V_f}{V_{\mathrm{Re}\,q}} & V_f < V_{\mathrm{Re}\,q} \\ 1 & V_f = V_{\mathrm{Re}\,q} \end{cases} \tag{11}$$

8) Calculate system utility in two types:

First, system utility defined for systems that faced to water shortage: $Utility = e_p \times A_{op}$

Second, defined for systems that faced to water surplus: $Utility = e_p \times e_{op}$

9) Calculate volume of required water in networks (water demand) (V_{Req}) by:

$$V_{\mathrm{Re}\,q} = V_{\mathrm{Re}\,q1} + V_{\mathrm{Re}\,q2} \tag{12}$$

where V_{Req1} is volume of required water resulting from increase in cultivated area because of investment in renovation plans execution and V_{Req2} is increasing volume of required water resulting from change of crop pattern.

$$V_{\mathrm{Re}q1} = A \times h_{\mathrm{Re}q} \times OP \tag{13}$$

$$V_{\mathrm{Re}q2} = A \times h_{Inc} \times OP \tag{14}$$

where A is cultivated area, h_{Req} is required water depth for crops in ha (for Qazvin Irrigation Network is 0.42) and h_{Inc} is increasing water depth resulting from change of crop pattern (for Qazvin Irrigation Network is 0.0632).

2.5 Rehabilitation of irrigation networks using system dynamics approach

Problem definition: The first step is to identify one or more key variables whose behaviors over time define the problem. In rehabilitation of irrigation systems, to show the system performance, the network utility has been defined as a reference indicator indicator.

System description: In the present paper, the following variables have been assumed as endogenous: 1) water demand; 2) execution of rehabilitation plans; 3) limitation of available water resources. To indicate a dynamic hypothesis, the system archetypes and causal loop diagrams should be identified first. Two major archetypes dominate the Irrigation Network under study, which are “Limits to Growth” and “Fixes that Fail” Archetypes. The Limits to Growth archetype causes leveling off Reinforcing loops due to balancing mechanisms coming into effect (Senge, 1990). This archetype states that a reinforcing process of accelerating growth (or expansion) will encounter a balancing process as the limit of that system is approached.

The Fixes that Fail archetype leads in a reinforcing behavior due to interaction of balancing and reinforcing loops (Bagheri and Hjorth 2007). This archetype states that a quick-fix solution can have unintended consequences that exacerbate the problem. It hypothesizes that the problem symptom will diminish for a short while and then returns to its previous level, or become even worse over time (Braun, 2002).

In rehabilitation of irrigation networks, the effects of reinforcing mechanisms in a “Limits to Growth” archetype can be visualized in terms of government’s investment in renovation plans, agricultural development with increase in the cultivated area and change of crop patterns leading to increase in water demand. The effects of reinforcing mechanisms lead to an overexploitation of groundwater resources and decreasing utility resulting from a growing trend of water demand compared with the capacity of water supply due to agricultural development (Figs. 5 & 6).

The Fixes that Fail archetype is a combination of one reinforcing and one balancing loops. This archetype and its behavior over time – for example - in Qazvin Irrigation Network are shown in Figures 7 and 8, respectively.

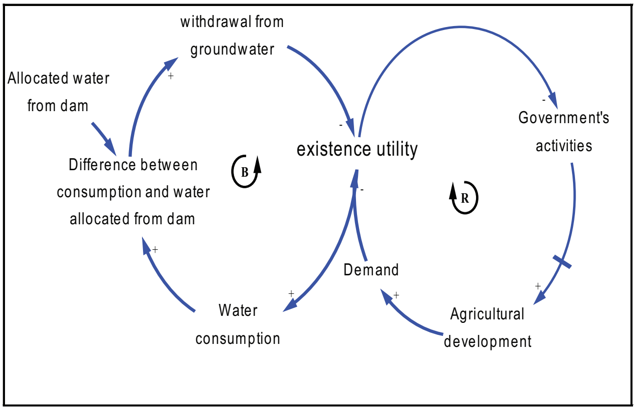


Fig. 5. Limits to Growth Archetype in irrigation networks

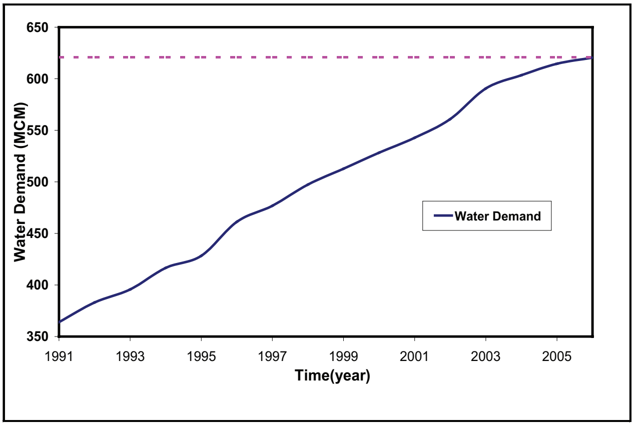


Fig. 6. Behavior over time in Limits to Growth Archetype for Qazvin Irrigation Network

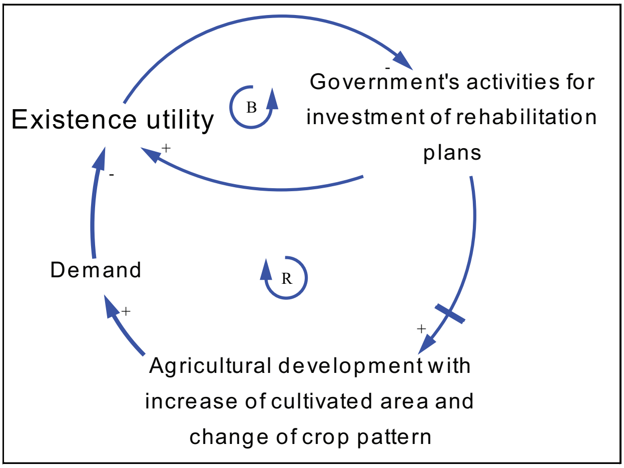


Fig. 7. Fixes that Fail Archetype in irrigation networks

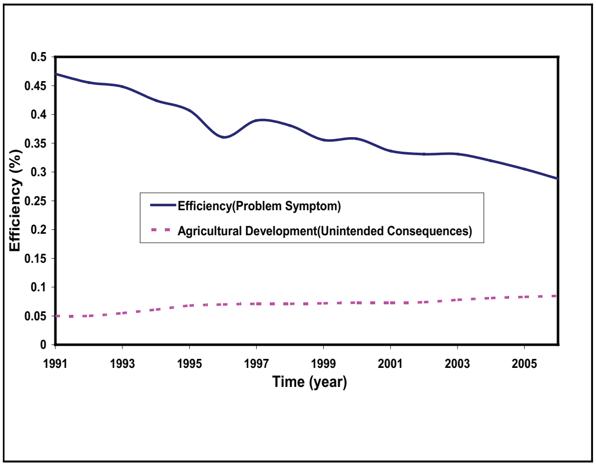
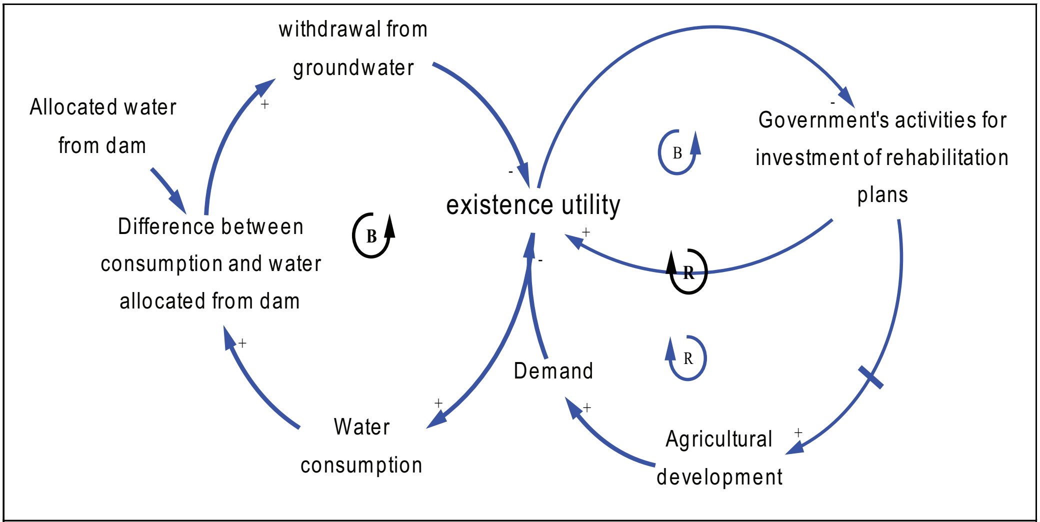


Fig. 8. Behavior over time in Fixes that Fail Archetype for Qazvin Irrigation

3. RESULTS AND DISCUSSION

Based on the recognized archetypes the conceptual model of irrigation networks is depicted in Fig. 9.



Comments:

Agricultural development: *This variable indicates the increase of cultivated area and change of crop pattern to increase demand*
Government activities: *It is assumed investment in renovation activities*

Fig. 9. Conceptual model of irrigation networks

Dynamic hypothesis: Based on the causal loop diagrams and irrigation networks archetypes, two dynamic hypotheses have been identified.

a) Dynamics of renovation plans execution (Fig. 10)

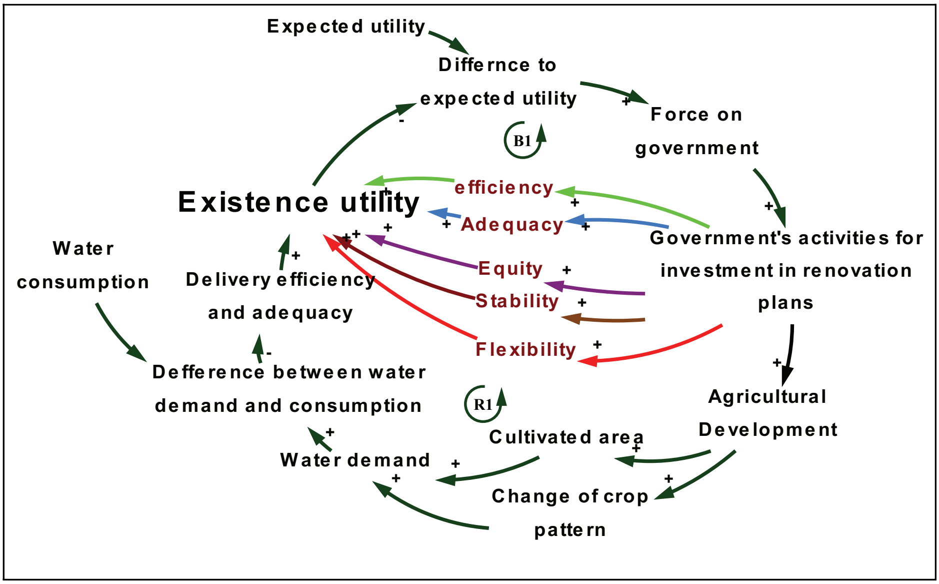


Fig. 10. Renovation plans execution causal loop diagram

b) Dynamics of demand growth and limitation of water resources (Fig. 11).

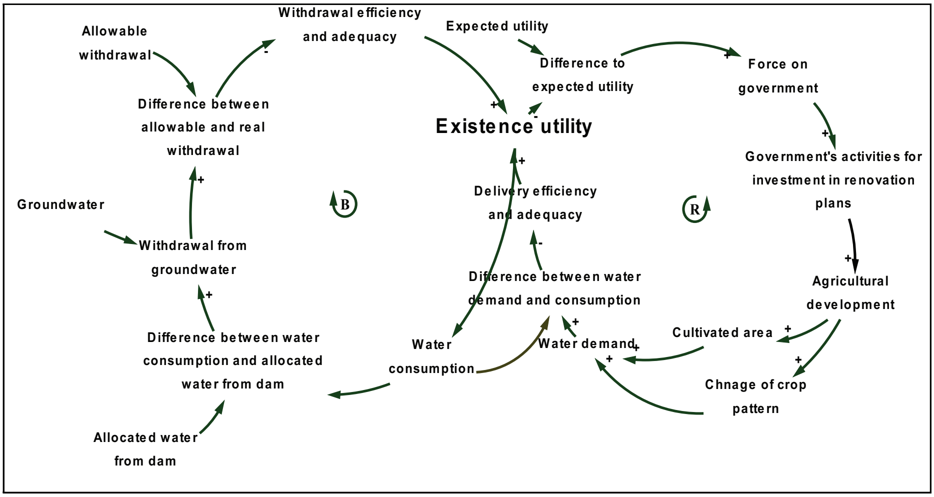


Fig. 11. Demand growth and limitation of water resources causal loop diagram

Model development (Qazvin Irrigation Network)

The model was developed using Vensim PLE version 3.0 software (Ventana Systems Inc., 1998). Figures 12 and 13 show progressively representations of the Qazvin Irrigation network Diagrams.

Two dynamic mechanisms are working to affect the “Existing system utility”. The first is responsible for “Investment in renovation plans execution”. As demonstrated in Fig. 13, this mechanism consists of two sides. The one shown as a balancing loop will increase the “Efficiency” due to decreasing the trend of “Losses”. The second one, shown as a reinforcing loop, will stimulate agricultural development which is named as “increase in cultivated area” and “change of crop pattern”. The “Average water demand” also varies according to these two terms. The “Delivery efficiency or adequacy” depends on both the amount of “Average water demand” and “Agricultural water use”. While the volume of “Average water demand” is more than “Agricultural water use”, the situation will be considered as adequate delivery; otherwise delivery efficiency will be applied.

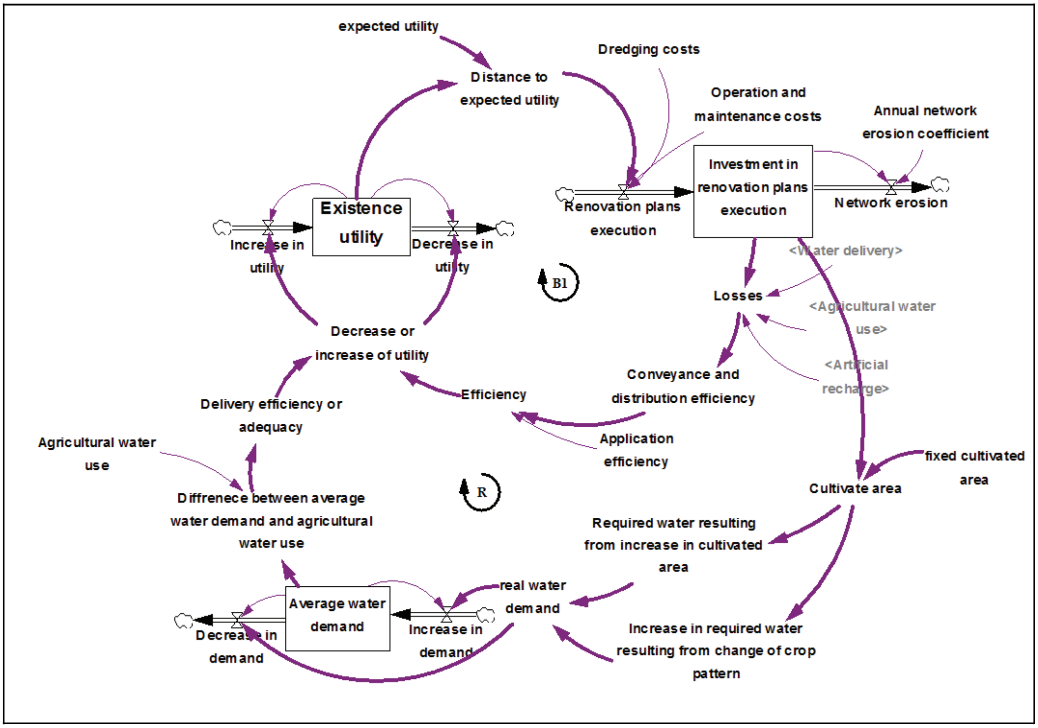


Fig. 12. The flow diagram model- The mechanism of rehabilitation plans execution

The second mechanism which affects the “Existing system utility” is withdrawal of groundwater which should be less than the allowable limit. As demonstrated in figure 14, “Real withdrawal” depends on the Difference between “allocated water from dam and agricultural water use”. In this stage, “withdrawal efficiency or adequacy” is defined based on the allowable and real withdrawal capacities. Finally, “Efficiency”, “Delivery efficiency or adequacy” and “withdrawal efficiency or adequacy” have been aggregated into one index named as “existing Utility.

Data of water volume delivered to Qazvin Irrigation network (V_{Ent}), volume of artificial recharge (V_{Rech}), volume of agricultural water use (V_{Cons}), withdrawal volume of groundwater (V_{Draw}), volume of effective rain (V_{Er}), application efficiency (e_a), cultivated area (A), operation and maintenance costs (P_{main}) and dredging costs (P_{dredg}) was available from 1991 to 2006 (Siahi, 2007 and Hashemi, 2008).

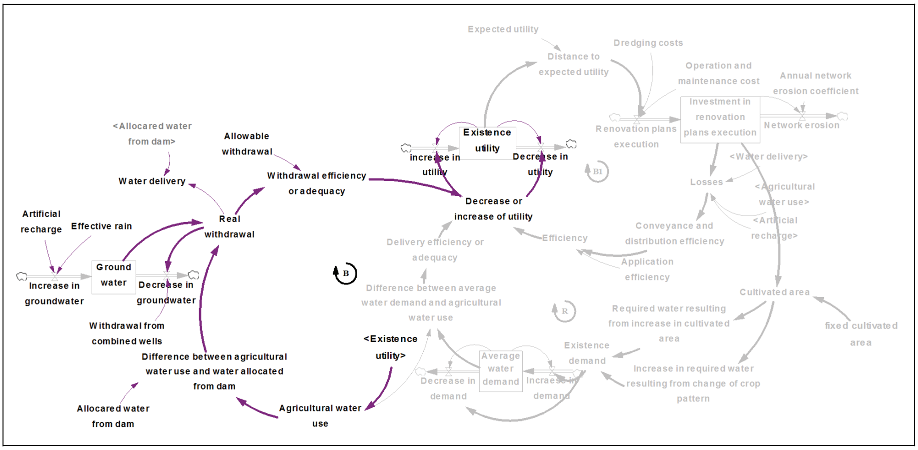


Fig. 13. The flow diagram model- The mechanism of demand growth and limitation of water resources

Model verification: It comprises establishing the structural and behavioral validity of the model with respect to the modeling purpose. When structure of the model is sufficiently reliable, the accuracy of the model behavior is significant. Behavior validation is typically performed, after structural validation. In behavior validity tests, pattern prediction has more priority than point prediction, because of long-term orientation of the models (Barlas, 1996). Although validation is applied to every stage of modeling, for detection of structural flaws formal procedures and some individual tests called 'structure-oriented behavior tests' are used (Barlas, 1996; Forrester and Senge, 1980). A minimum crucial set involves the use of *extreme-condition, behavior sensitivity and phase relationship* tests (Barlas, 1996).

a) *Extreme-condition* tests involve assigning extreme values to selected model parameters and comparing the model generated behavior to the anticipated behavior of the real system under the same extreme condition. The cultivated area is set to an extremely small value (zero) and the dynamic behavior for water demand is observed that it would be zero too; and the renovation plans execution is set to an extremely high value and the dynamic behavior for conveyance and distribution losses is observed that it would be zero. Figure 14 is a simulation run of an extreme condition test.

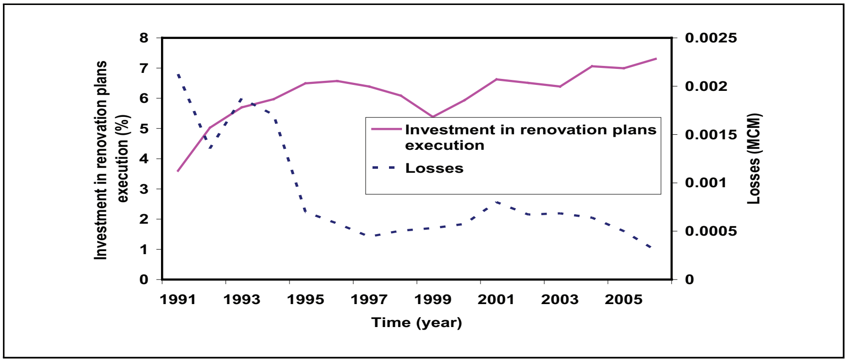


Fig. 14. Simulation run of an extreme condition test on renovation plans

b) *Behavior sensitivity* tests consist of determining those parameters to which the model is highly sensitive and asking if the real system is also sensitive to those set of parameters. The renovation plans execution which is subjective to the model's behavior has been verified against "conveyance and distribution efficiency" with two different coefficients 2 and 0.5 in equation (5). It was shown that the results were not much sensitive to the values of those functions, instead, what were more important were their shapes

In Fig. 15 the results of sensitivity test are demonstrated for a sample function. Finally, the comparison of the model results with the observed ones is depicted in Fig. 16.

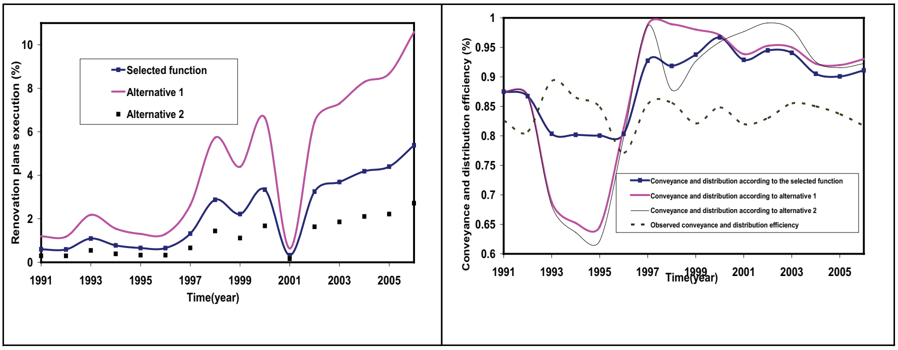


Fig. 15. Sensitivity analysis on the function of the effect of renovation plans execution on conveyance and distribution efficiencies

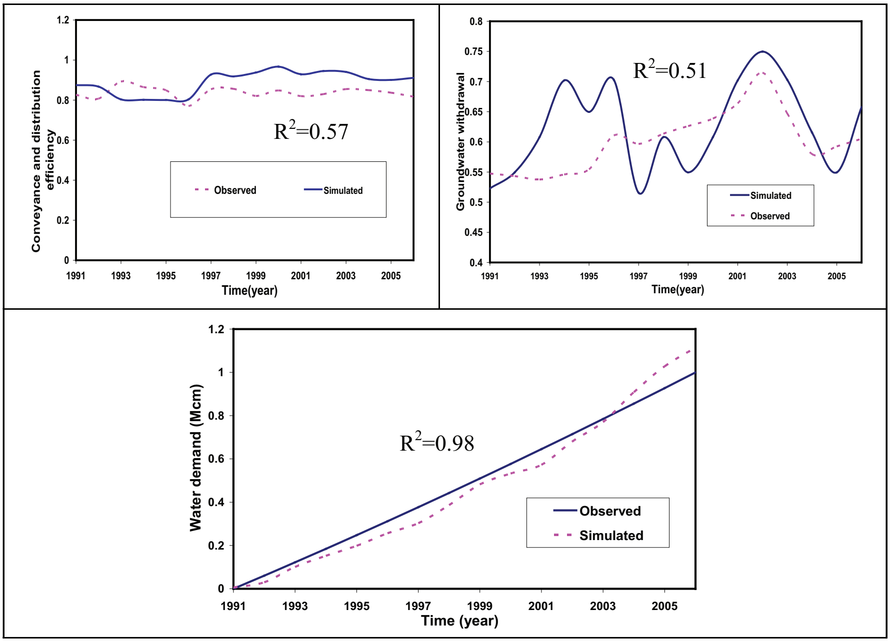


Fig. 16. The comparison of final model behaviors with those of observed for "Groundwater withdrawal", "Conveyance and distribution efficiency" and "Water demand" according to the simulated data.

Model simulation and policy analysis

When the model structure has been validated, it can be used to test the effect of policy interventions on the problem. This includes studying the model structure to identify policy levers, then simulating the effect of those changes.

The purpose of the model is to design policy alternatives that would be effective in rehabilitation of irrigation networks sustainability in the long term. Three strategies for network rehabilitation are considered as: 1- fixing the area under cultivation, that prevent increasing trend of agricultural development and activate reinforcing loop in “Fixes that fail” Archetype with making the water consumption increase; 2- decreasing withdrawal of groundwater less than allowable withdrawal that activates balancing loop in “Limits to growth” Archetype with control of water demand and prevent increasing trend of groundwater withdrawal; 3- and investment in renovation projects that activates balancing loop in “Fixes that fail Archetype” with decreasing of physical and management losses.

Existence utility and its difference with the expected utility are shown in figure 17 from 1991 to 2011. As can be observed from the figure, the trend of existence utility variation is decreasingly from 1991 to 1998 before rehabilitation activities has been improved, while its decreasing trend has been milder from 1998 to 2006 and will have increasing trend to 2011. It has been expected that with dynamics of renovation plans execution, increasing trend of utility should be steeper but dynamics of demand growth and limitation of water resources controls this mechanism and only diminish the utility decreasing trend. That condition states that rehabilitation activities cause to fix or –sometimes- increase the utility from 1998.

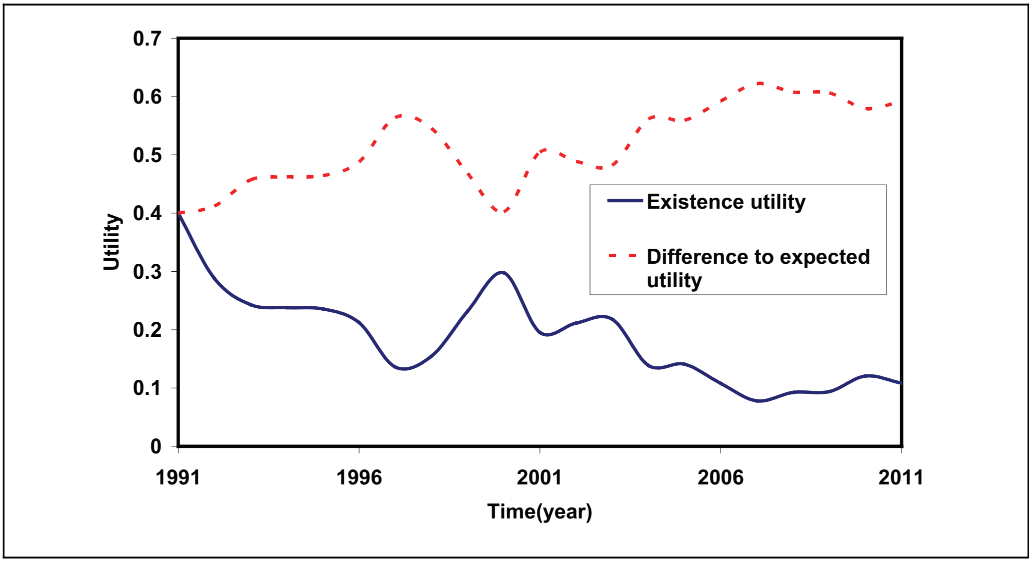


Fig. 17. Existence utility and difference to expected utility in Qazvin Irrigation network under BAU strategy

The above strategies underpin the policies which could be adopted to lead the system utility to equilibrium and help to sustain the system under study. To investigate the effectiveness of the proposed policies the system has been simulated for a period of 1991 till 2011. Model analysis reveals that, policy experiments create significant modifications not only to the behavior of the specifically intended components but also to the system as a whole (Saysel, 1999).

Investment in networks renovation until its effect on utility becomes constant: irrigation network should be renovating because of poor design and operation, lack of sufficient maintenance and poor management. This policy was simulated and the result is depicted in Fig. 18. In fact, with control of renovation plans execution dynamics, system utility will increase and in 2011 will be 4% more than current situation. Firstly, that policy increases utility fast; however, the growing trend of utility decreases in time.

Decreasing withdrawal of groundwater less than allowable withdrawal: Now, with increasing withdrawal of sure discharge from groundwater aquifer, groundwater table will declinecontinuously. The result of mentioned policy is shown in Figure 19. Then, with control of groundwater withdrawal – in fact control of water consumption – system utility in 2011 will increase 6% more than current situation. In this policy, the growing trend of utility is more stable than other policies; because it increases utility in a constant speed and intensity.

Fixing the area under cultivation in year 1991: The above mentioned policy was simulated and the result compared with the existence utility (Figure 20). With control of cultivated area – in fact control of water demand – utility will increase and in 2011 will improve up to 10% compared with current situation. That policy increases utility in time; however, the growing trend of utility decreases in the last years.

With comparing the Figures 18, 19 and 20, one can observe that the “Fixing the area under cultivation” policy is more effective than the other policies; but “Decreasing withdrawal of groundwater” policy is the most stable one to increase the utility. Therefore, in order to improve system utility in irrigation networks, these policies must be taken.

The increasing trend in agricultural development, which is mostly ignored in other studies, should be paid more attention when planning for investment in renovation plans. This feedback structure activates the reinforcing loop in the “Fixes that fail Archetype” and makes growth in the water demand. This growth causes a tendency to overexploit the groundwater resources due to water deficit resulting from a growing trend of water consumption. That process, in a long term, leads to reduction of water resources carrying capacity. Ignoring the carrying capacity of water resource will result in degradation of resources and decrease in their renewability capacity in a long term.

With control of agricultural development in irrigation networks, R1 (figure 13) could be tackled and the utility will be enhanced. On the other hand, investment on renovation plans leads to improving the utility indices without increasing in water demand. In addition, water consumption will be also controlled and overexploitation of groundwater will decrease.

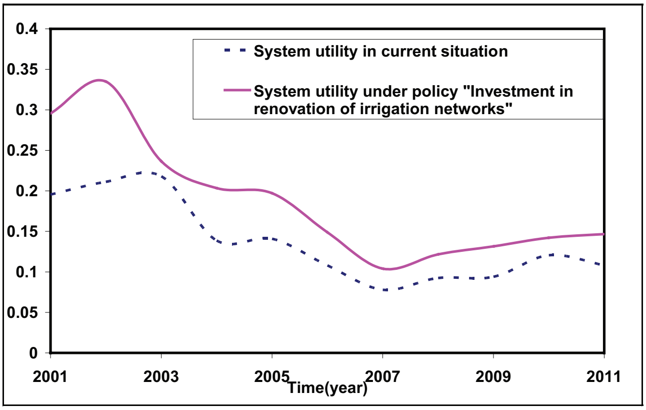


Fig. 18. Trends of the system utility variation according to “Investment in irrigation networks rehabilitation” policy

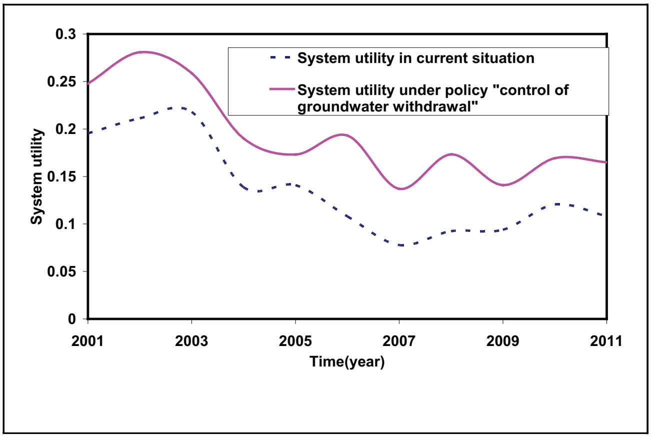


Fig. 19. Trends of the system utility variation according to “Decreasing withdrawal of groundwater” policy

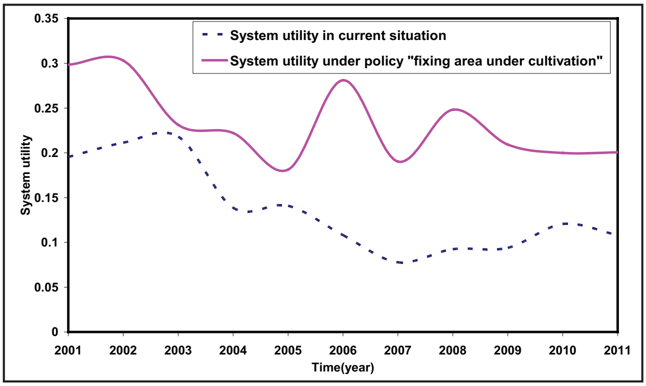


Fig. 20. Trends of the system utility variation according to “fixing the area under cultivation” policy

The variation of total efficiency is depicted in Fig. 21, given that current perception was continued compared with these three policies imposed. It shows that when those policies are not imposed in a long term, degradation of resources and unsustainable system will be happened but with applying those policies, system could be worked sustainable and in long term, system utility would be stabled.

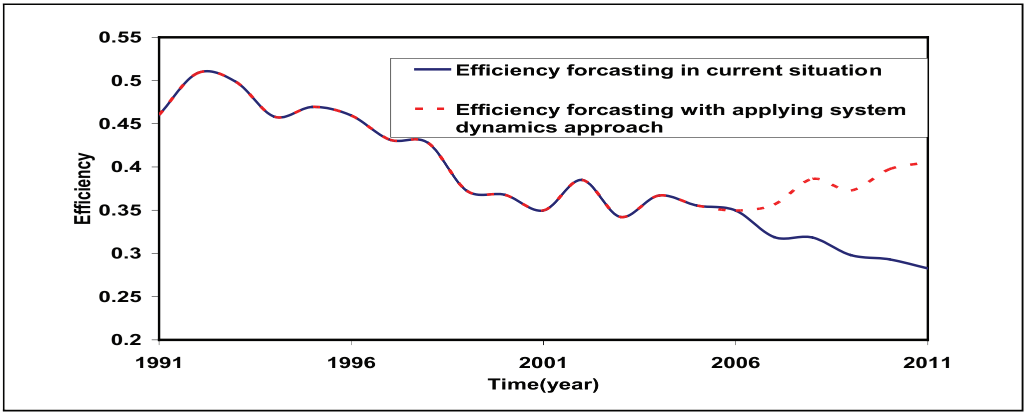


Fig. 21. Efficiency forecasting with applying current perception compared with system dynamics approach under combined policy

4. CONCLUSIONS

A system dynamics methodology for rehabilitation of Qazvin Irrigation Network was presented in this paper.

- Improving of system utility is the main target in rehabilitation of irrigation networks that needs integrated and systemic studies with considering the impacts of various factors and their relationships.
- System dynamics approach helps better recognition of the effective mechanisms on rehabilitation of irrigation networks. With applying this methodology, the realistic perception of system behavior and long- term impacts could be achieved that will be more effective for decision makers.
- Improvement of irrigation networks rehabilitation model with applying system dynamics approach could represent the key feedback structures in the irrigation networks; For example feedback of efficiency, adequacy, equity, stability and flexibility on crop pattern changes and on cultivated area and finally on system utility could be considered.
- The most important feedback structure that is ignored in previous studies is increasing trend in agricultural development because of investment in renovation plans. This feedback structure activates reinforcing loop in “Fixes that fail Archetype” and makes growth in water consumption.
- This growth causes a tendency to overexploit the groundwater resources due to water deficit resulting from a growing trend of water consumption. That process, in a long term, leads to reduction of water resources carrying capacity.
- Rehabilitation of irrigation networks with applying system dynamics approach was run in

Qazvin Irrigation Network considering to efficiency index. Present paper with considering to two dynamic hypotheses, dynamic of renovation plans execution and dynamic of demand growth and limitation of water resources, has been investigated.

- With control of renovation plans execution dynamics and demand growth and limitation of water resources dynamics, system utility will increase. With control of cultivated area, groundwater withdrawal and renovation plans execution, system utility will improve to 10%, 6% and 4% respectively compared with current situation. With comparing these policies, one can observe that the "Fixing the area under cultivation" policy is more effective than the other policies; but "Decreasing withdrawal of groundwater" policy is the most stable one to increase the utility.
- With control of agricultural development in irrigation networks, investment on renovation plans leads to improving of utility indices without increasing trend in water demand. Also water consumption is controlled and overexploitation of groundwater will be decreased.
- Results show that when those policies are not imposed in a long term, degradation of resources and unsustainable system will be happened but with applying those policies, system could be worked sustainable and in long term, system utility would be stabled.
- Present paper shows that in Qazvin Irrigation Network, system utility doesn't improve only with increasing of investment in renovation plans execution, but groundwater withdrawal and cultivated area should be controlled concurrently too. This is an important result that could be studied for other networks.
- In fact, system dynamics methodology is applied not only for integrated perception of irrigation networks but also to recognize irrigation networks and their problems and to make effective decisions to stabilize the system utility.

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