Vol. 11, No. 4 (2022) : 688 - 699
DOI : http://dx.doi.org/10.23960/jtep-l.v11i4.688-699

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Increasing Irrigation Efficiency through Maintenance of Irrigation Network Based on Dynamic Simulation

Mislaini Rahman [1]✉, Bambang Pramudya N [2], M Yanuar J Purwanto [3], M Solahudin [2]

[1] Agricultural Engineering Program, IPB University, Darmaga Campus IPB, Bogor, INDONESIA
[2] Department of Mechanical and Biosystem Engineering, IPB University, Darmaga Campus of IPB, Bogor, INDONESIA
[3] Department of Civil and Environmental Engineering, IPB University, Darmaga Campus IPB, Bogor, INDONESIA

Article History :
Received : 20 September 2022
Received in revised form : 5 December 2022
Accepted : 25 December 2022

Keywords :
Asset Damage,
Efficiency,
Farmer's Contribution,
Government Budget,
Maintenance

✉Corresponding Author:
mislaini_rahman@yahoo.co.id

ABSTRACT

Given the increasing demand for water, it is necessary to make an effort to anticipate water scarcity through increasing efficiency in an irrigation area. Increasing efficiency requires an increase in the contribution of farmers to finance the repair of irrigation canals. The purpose of this study is to formulate a financing scheme for maintenance of irrigation networks by the state and farmer participation (contribution). Research was conducted at the Cihea Irrigation Area (Cianjur Regency). The method used is system dynamics modeling by observing the parameters studied, including; asset damage, productivity, farmer contributions, public works budget and irrigation efficiency. The results of the analysis with dynamic simulations show that the best scenario to reduce damage to Cihea Irrigation assets is scenario 2 because it reduces the damage by 10.29% and increases the irrigation maintenance index by 0.05 within 10 years. Thus, it is necessary suggest to the government and farmers to increase the contribution and budget for the improvement of the Cihea Irrigation.

1. INTRODUCTION

The availability of water for agricultural land in Indonesia is quite available. However, with population growth and the need for land, the need for water will continue to increase, this results in the availability of water for agriculture being threatened. Pemerintah Indonesia (2006) stated that the function of irrigation is to support agricultural productivity in increasing national food security and the welfare of the community, especially to farmers, moreover, for the success of the government's program in pursuing a rice surplus, it is necessary to support good irrigation infrastructure. Haposan *et al.* (2019) stated the need for water management through an irrigation system to regulate the distribution of water to agricultural land which will increase agricultural productivity in an area.

Water availability is the amount of water that is estimated to be continuously available in rivers and rainwater that falls deep with a certain period (Kendarto *et al.* 2021). Based on Law No. 7 of 2004 article 29 (3) concerning the allocation of resources for the provision of irrigation water for crop needsor people's agriculture through an irrigation system is a top priority in the framework of developing water resources (Pemerintah Indonesia, 2004). Given its strategic importance, it is necessary to optimize the availability of water in irrigation areas, including the Cihea irrigation area. This is based on the fact that the main priority of irrigation development in Indonesia is still aimed at irrigation management to support the agricultural sector.

Given the increasing demand for water, it is necessary to make an effort to anticipate water scarcity through increasing efficiency. The low efficiency is due to inadequate channel maintenance. Increased efficiency requires an increase in the contribution of farmers to finance the operation and maintenance of irrigation, which is needed to support the sustainability of efficient irrigation performance. This is one of the important agendas in irrigation reform that emphasizes the participation and independence of farmers as stated in the Irrigation Management Policy Renewal Program.

One of the study approaches to provide policy direction for irrigation management to improve efficiency is through a dynamic system. The model is developed according to the purpose. Modeling is a very important activity both to know the behavior of the system and to control it (Abidin, 1997). The purpose of this study is to formulate a financing scheme for the maintenance of irrigation networks by both the government (Real Need for Operation and Maintenance) and farmers (contribution).

2. MATERIALS AND METHODS

This study was carried out in the Chihea Irrigation Area, Chianjur District. The Chihea Irrigation Zone is the oldest technical irrigation system built by the Dutch government between 1879–1904 and started operating in 1914. Administratively, the Chihea Irrigation Zone is located in three subdistricts, namely Bojongpikung Subdistrict, Chiranjang Subdistrict and Haurwangi. subdistrict, Cianjur Regency. The Chihea Irrigation Area has an area of 5,484 hectares of paddy fields. Pursuant to article 41 of Law No. 7 of 2004 on water resources. Irrigation areas of more than 3,000 ha are administered by the central government (Pemerintah Indonesia, 2004). Therefore, at Cihea irrigation area, the government carries out participatory activities on an ongoing basis to improve irrigation networks in order to support optimization of adequate water availability. Participatory construction involves associations of farmers using water as a form of cooperation in irrigation management.

The tools used in this research are a set of computers and powersim software. The data needed in this study are hydrological data in the form of discharge and rainfall data, land use data at the research location, irrigation network infrastructure data and socio-economic conditions of farmers in Cianjur Regency.

2.1. Research Procedure

This study uses a system dynamics approach. According to Forrester (1994), system dynamics is a framework that focuses on the system think in terms of feedback loops and take a few additional steps to structure and test it through a computer simulation model. The research method used is field observation by observing the parameters studied, primary and secondary data collection on the Cihea irrigation system.

In carrying out a systems approach there are several stages of systematic work that must be considered. The stages of the systems approach include: requirements analysis, problem formulation, system identification, system modeling and model validation. Pramudya (1989) explains that the model is a state of abstraction from the real situation or is a simplification of the real system to facilitate the study of a system. According to Richardson (1986) models can reveal and explain the relationships of various components, actions and reactions and causal relationships. A good model is a model that describes all the things that are important from the real world in a particular problem. statement by Sugandi *et al*., (1998) this systems approach has several elements, including the presence of a planning and management methodology, is interdisciplinary and organized, is capable of non-stop quantitative thinking using mathematical models, modeling and optimization methods, and can be applied using a computer. The stages of work can be seen in Figure 1.

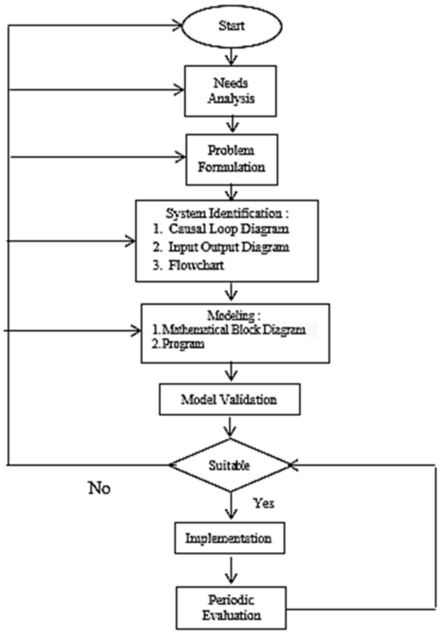

Figure 1. Stages of work in the system approach

For the creation of a dynamic system model, it is necessary to develop a general conceptual framework called causal loop diagram (CLD) and stock and flow diagram (SFD) to measure and simulate the model (Sterman, 2000). The CLD of irrigation maintenance shown by Figure 2.

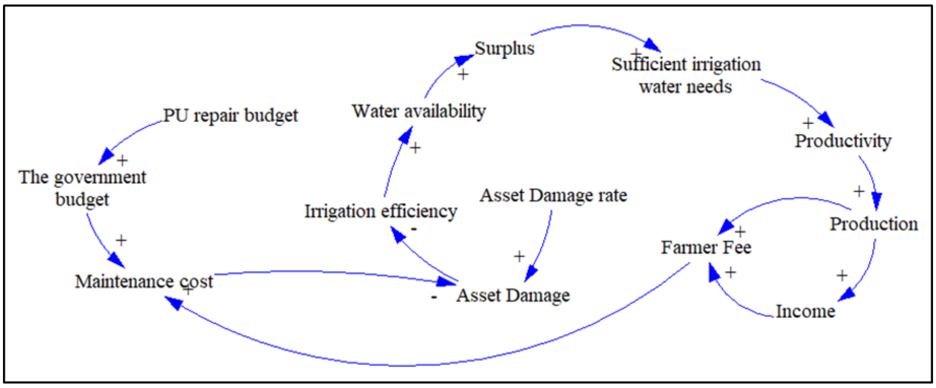

Figure 2. Causal loop diagram of irrigation canal maintenance

This causal diagram is purposed to find out the root cause or to show the root cause and quality characteristics of the causal factors. Sánchez *et al*., (2009) explains that Causal analysis was created as a quality control tool and to identify potential factors causing a common effect caused by the various phenomena under study.

Based on the CLD that has been prepared, an SFD is created which will describe the flow structure to build a mathematical model (Waliulu & Adi, 2021). Some of the equations built in the mathematical model to measure how many parameters to increase the efficiency of irrigation canals are as follows:

- Maintenance Index = 'Irrigation Maintenance' / 'Asset Damage'
- Asset Damage Rate = ('Asset Damage Number'*'Asset Damage')
- Irrigation Efficiency = (('F Irrigation'*1)+'Irrigation Maintenance')/1

2.2. Model Validation

The method used to validate is Root Mean Square Percentage Error (RMSPE). The smaller the RMSPE value, the higher the level of validity. The RMSPE method can be seen in Equation 1.

$$RMSPE = \sqrt{\frac{1}{n}\sum_{n=1}^{n}\left(\frac{S_t - A_t}{A_t}\right)^2} \quad (1)$$

where St is simulation value at time *t*; At is actual value at time t; and n is the number of observations (t = 1,…, n). According to (Rachmawati, 2016), the interpretation of the final RMSPE value is as follows: Error < 5% means very valid in describing existing conditions, 5% < Error < 10% means valid in describing existing conditions, Error > 10% means invalid in describing existing conditions.

2.3. Model Scenario

The use of this scenario aims to determine how rigid the system is and how, if there is a certain scenario, it can create a good effect if the existing scenario is added (Shiddekh & Suryani, 2018). The model scenario is a simulated policy direction analysis. The scenario was developed after going through the validation stage. In this research, the scenarios carried out are:

1. Scenario 1: Increase the government budget for irrigation by 10% and farmer contributions by 5%.
2. Scenario 2: Increase the government budget for irrigation by 20% and farmer fees by 10%

3. RESULTS AND DISCUSSION

3.1. Area Condition

Geographically and administratively, the Cihea Irrigation Area is a plain area located in three sub-districts, namely Bojongpicung, Haurwangi and Ciranjang Districts, with an area of irrigated rice fields reaching 5,484 ha. The irrigation area is irrigated from the Cisokan weir with water from the Cisokan River. Irrigation efficiency in 2019 was around 67%. The distribution of water in the Cihea Irrigation Area is divided into 3 (three) groups and serves 28 villages from 3 sub-districts, namely: Category I, Bojong Picung sub-district, covering an area of 1,863 ha, Group II, Haurwangi sub-district, covering an area of 1,852 ha and Group III Ciranjang sub-district covering an area of 1,769 ha. The location map of the Cihea Irrigation Area is presented in Figure 3.

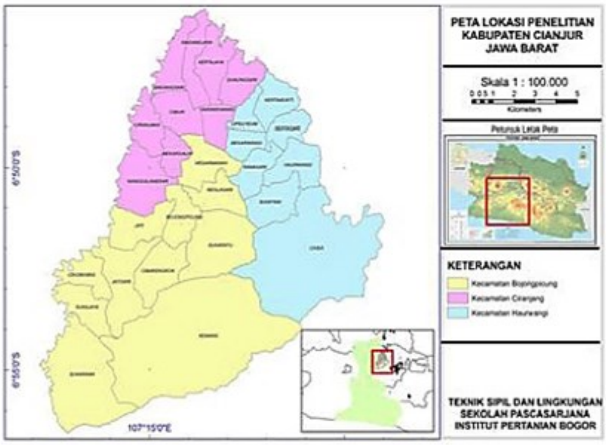

Figure 3. Research site map

Farmers in Cihea Cianjur are farmers with rice and secondary crops. Planting intensity 2 times planting rice and 1 time planting palawija in one year. The rice varieties used were Ciherang, Mekongga and IR 64. The average production was 5.6 tons per hectare with a production cost of IDR 3,000,000.00 per hectare. The cultivated crops are soybeans. The varieties used were Argo Mulyo, Anjasmoro, MS Dapros, Burangrang and Raja Basa. Average production of 1.5 tons/hectare (Anika, 2011)

3.2. Irrigation Network Condition

The condition of the irrigation network of several Cihea irrigation canals can be seen in Figure 4.

Figure 4. Existing condition of Cihea irrigation area

The physical condition of the irrigation network is assessed based on the level of damage compared to the initial conditions. The current condition of the Cihea Irrigation network is in a state of wide crack, eroded, peeling. This condition belongs to the moderately damaged category according to Table 1.

This damage indicator is in line with the magnitude of the efficiency based on observations in the existing field in a state of minor damage which will have an efficiency of 66%. Damage to irrigation networks caused by natural disturbances, age of construction and less than optimal irrigation management of irrigation infrastructure (Kementerian PUPR, 2015) and damage to the entire irrigation network, causing water loss which in the end the overall average irrigation efficiency of the irrigation network is low (Bunganaen, 2005).

Table 1. Indicators of damage to irrigation assets and their descriptions

Damage rate	Category Condition	Damage
0 – 20 %	Well	Hair crack
20 – 40 %	Slightly damaged	Wide cracks, eroded, peeled and weathered
40 – 80 %	heavily damaged	Visible steel reinforcement, hollow, bent or curved, shifted from its proper place, tilted from the upright position, part of the building lowered its elevation, and there was water flow under the foundation
80 – 100 %	Total Damage	he whole building lowered its elevation and the building collapsed

Soucer: Kementerian PUPR (2015).

3.3. Participation in Maintenance Costs

Operational and maintenance cost for irrigation are obtained from the government and farmers. In the Cihea irrigation area, the involvement of farmers from planning to implementation, in general, has shown the participation of farmers, but in quality it is still far from expectations, especially in irrigation water fees (Sukayat *et al*., 2019). Normatively, it has been agreed in the deliberation that the water fee uses the size of a camel or 50 kg per ha per season. If efficiency can be increased, farmers' income will also increase so that farmers' contributions can be increased. The government budget for the improvement of Cihea Irrigation to date is around Rp. 2,215,000,000. -/year.

3.4. System Modeling

Preparation of system modeling by making stock flow diagrams, simulations, model validation and implications of model results.

a. Stock Flow Diagrams

The stock flow diagram for the maintenance of the Cihea irrigation network was compiled by connecting the main variables as described in the causal loop diagram. The model structure must also be a quantitative relationship and provide measurable outputs. Stock flow diagram of irrigation canal maintenance can be seen in Figure 5.

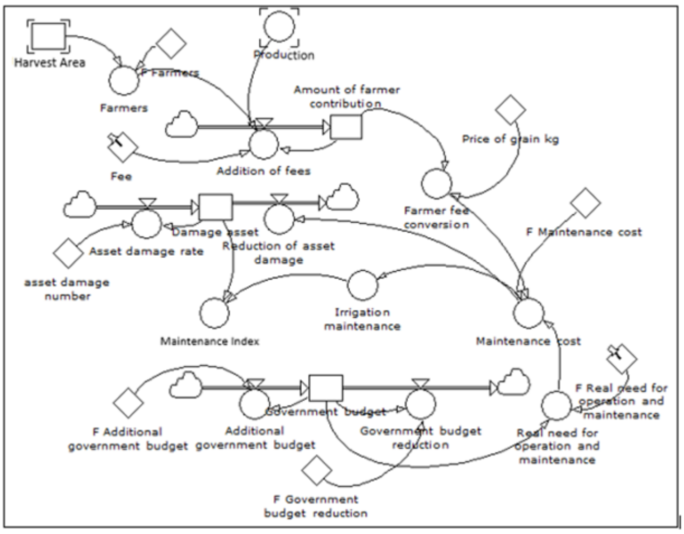

Figure 5. Stock flow diagram of irrigation channel maintenance

b. Modeling Results

The modeling results show a declining graph of asset damage data and maintenance index from 2018 to 2045. One of the causes of decreased asset damage is an increase in maintenance of irrigation network which leads to an increase in irrigation efficiency so that water can be utilized effectively. The condition of the existing damage to the Cihea irrigation canal can be seen in Figure 6.

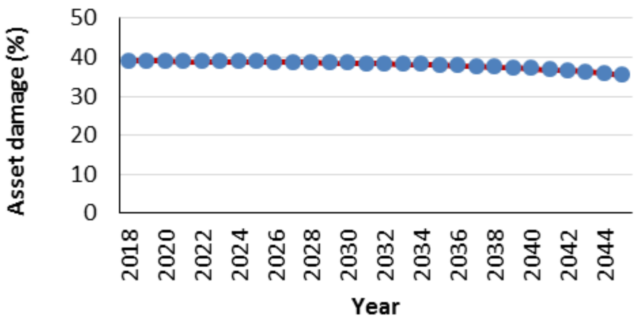

Figure 6. Conditions of damage to existing irrigation network

Based on the graphic above, condition of the irrigation network in 2018 was 39% and in 2045 it was 35.42%. Condition of the Cihea irrigation network is categorized as moderately damaged because it has a damage level of 21% - 40%. In accordance with Kementerian PUPR (2015), regarding the classification of condition of this irrigation networks as in Table 2.

Table 2. Classification of the physical condition of irrigation networks

Damage rate	Condition category
< 10 %	Well
10 % - 20 %	Light Damage
21 % - 40 %	Medium Damage
> 40 %	Heavy Damage

Source: Kementerian PUPR (2015)

Maintenance of irrigation networks needs to be improved irrigation performance. The performance of irrigation networks can be seen from the consistency of irrigation efficiency values. Sumaryanto (2006) stated that the decline in performance was caused by the degradation of the function of infrastructure in the irrigation system as well as the irrigation maintenance management. The degradation of infrastructure functions is caused, among others, by damage to infrastructure. The simulation results of the Cihea irrigation network maintenance index shown by the following figure.

The irrigation maintenance index in Figure 7 is still below 1, this indicates that the costs for maintaining the irrigation network are not sufficient for repairs. So to increase the maintenance index, it is necessary to increase the government budget and farmer participation in the form of contributions. Thus the damage can be repaired immediately and efficiency will increase. The relationship between asset damage and irrigation efficiency can be seen in Figure 8.

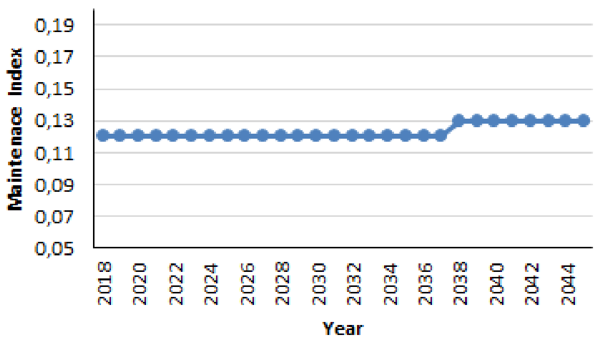

Figure 7. Cihea irrigation canal existing maintenance index

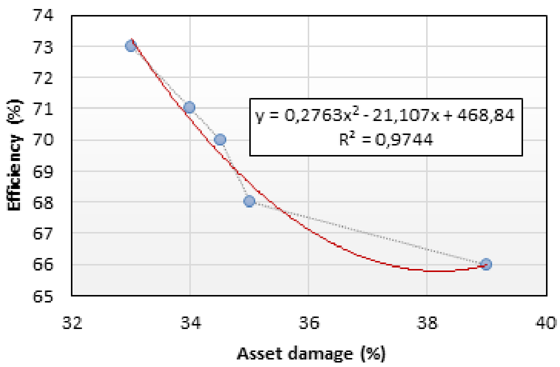

Figure 8. Relationship of damage to irrigation channel efficiency

Bolaños *et al*., (2011) stated that due to insufficient or poor network maintenance, it causes damage to irrigation networks and low irrigation system performance. The low irrigation efficiency is due to poor irrigation performance. In Figure 8 it can be explained that asset damage affects irrigation efficiency, this can be seen from the equation $y = 0.2763x^2 - 21.107x + 468.84$ which shows a linear relationship between efficiency and asset damage. As the number of asset damage increases, irrigation efficiency will decrease. This can be seen when the efficiency is 73% the damage rate is 32% and when the efficiency is 68% the damage rate increases to 36%.

c. Model Validation

The interaction between model variables must match the real system. Some of the variables used are asset damage, government budget, and rice production. Validation values for several variables in the Cihea irrigation network maintenance system can be seen in Figure 9-11 and Table 3.

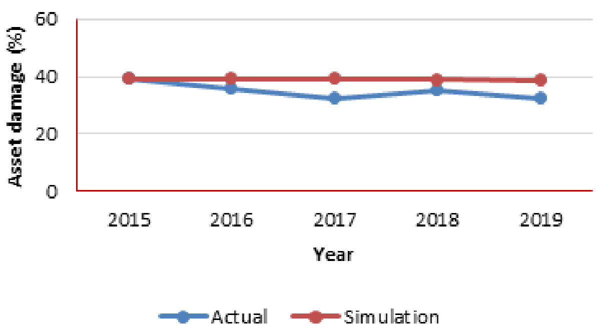

Figure 9. Validation of asset damage

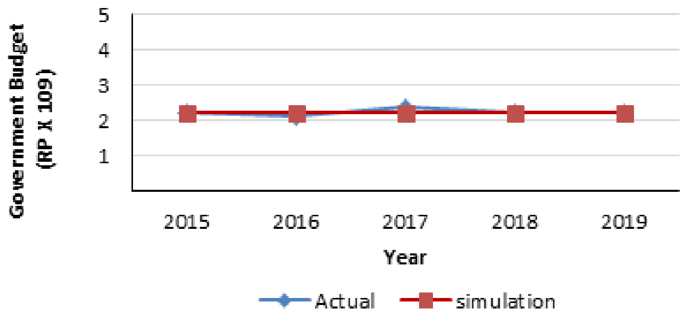

Figure 10. Validation of government budget

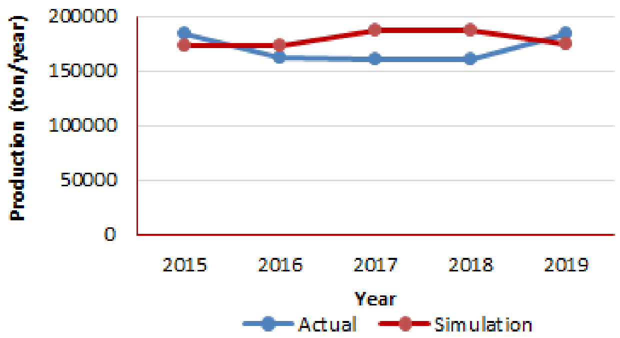

Figure 11. Validation of production model output

Table 3. Model validation test results

Variable	RMSPE	Description
Asset Damage	5.41%	Valid
Government Budget	0.14%	Very Valid
Rice Production	6.80%	Valid

Based on the model validation test, the data from the simulation results are in accordance with the actual data in the study. The variable damage to assets, government budget and rice production has an RMSPE value of less than 10% so that it can be said to be valid, acceptable and can be used in the irrigation channel maintenance model to improve irrigation efficiency in Cihea.

d. Implications of the model

The simulation results show that asset damage is decreasing due to the increase in the irrigation maintenance budget each year. This is also coupled with farmer participation in the form of contributions for each planting season. However, it is still necessary to design several scenarios to reduce asset damage so that efficiency will increase and farmers can increase rice production to support food security. The simulation results of asset damage with scenario 1 and scenario 2 can be seen in Figure 12.

Figure 12 shows that asset damage can be reduced by an increase in the government budget and contributions from farmers. In scenario 1, it can be seen that in a period of 10 years asset damage decreased by 5.40%, in this condition the government budget for irrigation was increased by 10%/year and farmer contributions increased by 5%/planting season. While in scenario 2, it can reduce asset damage by 10.29% by increasing the budget by 20%/year and increasing contributions by 10%/ planting season. Based on the results of these scenarios, scenario 2 reduces asset damage faster than scenario 1. This of course will also increase irrigation efficiency. The following is a graph of the scenario simulation results to increase the maintenance index.

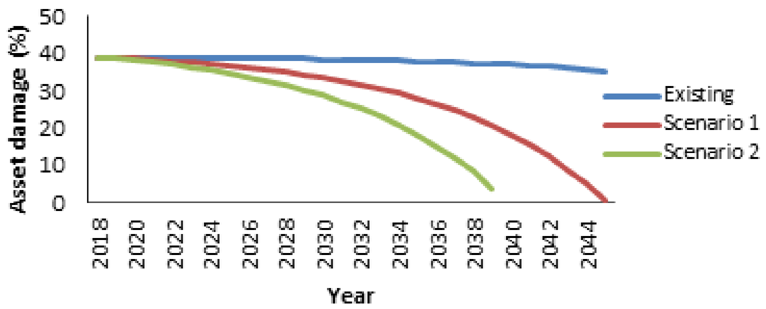

Figure 12. Scenario simulation results on damage to irrigation canals

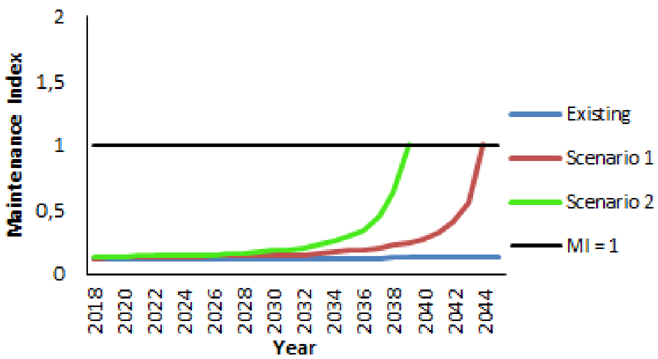

Figure 13. Scenario simulation results for changes in the maintenance index

In the existing condition, as shown by the graph, the irrigation maintenance index did not experience a significant increase. With the increase in the government budget and farmer contributions for irrigation maintenance, the maintenance index increases. In a period of 15 years, scenario 2 increases the irrigation maintenance index faster than scenario 1. The maintenance index number is the ratio of irrigation maintenance to asset damage, if the value is more than one, it means that maintenance costs are sufficient for repairing irrigation assets. This is seen in 2039 where maintenance index = 1.

4. CONCLUSION

The oldest technical irrigation in Indonesia is Cihea Irrigation which is an important irrigation infrastructure to support the food sector in Indonesia in general and West Java in particular. For this reason, it is necessary to maintain its efficiency by increasing the maintenance budget from the relevant government and farmer contributions. From the model that has been generated it can be concluded:

1. To improve irrigation efficiency, it is necessary to increase farmer fees and the government budget used for maintenance of irrigation assets.

2. The best scenario to reduce damage to Cihea Irrigation assets is scenario 2, reducing damage to 35.22% and increasing irrigation maintenance index to 1.23 within 20 years.
3. The increase in the government budget and farmer contributions provides an opportunity to support government programs in realizing food security programs and increasing farmers' income.

REFERENCES

Abidin, Z., Sutikno, P., Maryanto, I., & Santoso, I.B. (1997). Permodelan dinamik dan validasi model dari sistem kendali tangki ganda. *Mesin*, ***XII***(1), 14–23.

Anika, N. (2011). *Model Pengembangan Prasarana Usahatani Tingkat Tersier Di Lahan Sawah Beririgasi*. [*Master of Science Thesis*]. Institut Pertanian Bogor.

Bunganaen, W. (2005). Analisis efisiensi dan kehilangan air pada jaringan utama Daerah Irigasi Dagu. *Jurnal Teknik Sipil*, ***1***(1), 52–66. https://doi.org/10.35508/jts.1.1.80-93

Forrester, J.W. (1994). System dynamics, systems thinking, and soft OR. *System Dynamics Review*, ***10***(2-3), 245-256. https://doi.org/10.1002/sdr.4260100211

García-Bolaños, M., Borgia, C., Poblador, N., Dia, M., Seyid, O.M.V., & Mateos, L. (2011). Performance assessment of small irrigation schemes along the Mauritanian banks of the Senegal River. *Agricultural Water Management*, ***98***(7), 1141–1152. https://doi.org/10.1016/j.agwat.2011.02.008

Simorangkir, H., Ridwan, R., Kadir, M.Z., & Amin, M. (2019). Kinerja jaringan irigasi tingkat tersier UPTD Trimurjo Daerah Irigasi Punggur Utara. *Jurnal Teknik Pertanian Lampung*, ***8***(1), 49–56.

Kendarto, D.R., Suryadi, E., Sampurno, R.M., & Cahyabhuana, A.P. (2021). Daya dukung sumberdaya air dan indeks kekritisan air sub Das Cisokan Hulu. *Jurnal Teknik Pertanian Lampung*, ***10***(3), 402–412. https://doi.org/10.23960/jtep-l.v10.i3.402-412

Pemerintah Indonesia. (2004). Undang Undang Republik Indonesia Nomor 7 Tahun 2004 Tentang Sumber Daya Air. Sekretariat Negara. Jakarta.

Pemerintah Indonesia. (2006). Peraturan Pemerintah Republik Indonesia Nomor 20 Tahun 2006 Tentang Irigasi. Sekretariat Negara . Jakarta.

Pramudya, B. (1989). Permodelan Sistem Pada Perencanaan Mekanisasi Dalam Kegiatan Pemanenan Tebu Untuk Industri Gula [*Doctoral Thesis*]. Program Pascasarjana, Institut Pertanian Bogor.

Kementerian PUPR. (2015). Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia Nomor 23/PRT/M/2015 Tentang Pengelolaan Aset, (2015).

Rachmawati, L.F. (2016). Rekayasa Model Distem Dinamik Komoditas Jagung untuk Mendukung Program Upaya Khusus di Jawa Barat. [*Undergraduate Thesis*]. Institut Pertanian Bogor.

Richardson, G.P. (1986). Problems with causal-loop diagrams. *Archives*, ***2***(2), 158–170. https://doi.org/10.1002/sdr.4260020207

Sánchez-Román, R.M., Folegatti, M.V., & González, A.M.G.O. (2009). Water resources assessment at Piracicaba, Capivari and Jundiaí River Basins: A dynamic systems approach. *Water Resources Management*, ***24***(4), 761–773. https://doi.org/10.1007/s11269-009-9470-x

Shiddekh, M.A.I., & Suryani, E. (2018). Model sistem dinamik spasial untuk mengurangi tingkat kepadatan ruas jalan utama Kota Surabaya dengan metode *smart mobility*. *Jurnal Teknik ITS*, ***7***(1). https://doi.org/10.12962/j23373539.v7i1.28314

Sterman, D.J. (2000). System dynamics: Systems thinking and modeling for a complex world. In *Massachusetts Institute of Technology Engineering Systems Division*. https://doi.org/10.1016/s0016-0032(99)90164-3

Sugandi, D., Farmanta, Y., Astuti, U.P., & Wibawa, W. (1998). Upaya Peningkatan Produksi Padi melalui Pendekatan Sistem Dinamik dalam Mewujudkan Kemandirian Pangan di Provinsi Bengkulu. *Prosiding Seminar Nasional Hari Pangan Sedunia Ke-34*: *Pertanian-Bioindustri Berbasis Pangan Lokal Potensial*, 455 -464.

Sukayat, Y., Setiawan, I., Supyandi, D., & Bk, R.A. (2019). Petani dalam pengelolaan jaringan irigasi (kasus di Daerah Irigasi Cihea Kabupaten Cianjur). *Jurnal Ilmu Pertanian Dan Peternakan*, ***7***(12), 12–18.

Sumaryanto, S. (2006). Peningkatan efisiensi penggunaan air irigasi melalui penerapan iuran irigasi berbasis nilai ekonomi air irigasi. *Pusat Analisis Sosial Ekonomi dan Kebijakan Pertanian*, ***24***(2), 77–91. https://doi.org/21082/fae.v24n2.2006.77-91

Waliulu, Y.E.P.R., & Adi, T.J.W. (2021). A system dynamic thinking for modeling infrastructure project duration acceleration. *Procedia Computer Science*, ***197*** (2021), 420–427. https://doi.org/10.1016/j.procs.2021.12.181