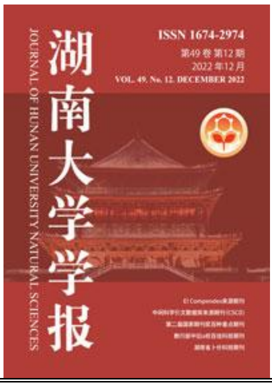

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Dynamics System Model for the Optimization of Irrigation Water Allocation

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Abstract: This paper intends to build the optimization of irrigation water allocation. The research method uses a dynamics system that the methodology consists of building the causal loop diagram that amplifies (positive feedback loop) or negates (negative feedback loop) for a change in a system variable. Water balance is an important aspect of using the water resources. Its existence can provide an overview of the balance sheet conditions between water availability and water needs over a specific period. The water balance sheet can show the status of water availability conditions, whether the status is already in deficit or still excessive. Irrigation as part of water resource management is a system in society that is dynamic and depends on the environmental conditions, mainly because of the variety of actors, the variety of uses, across the different administrative areas and different cultures. This condition is further aggravated by the reduction in water sources that can be used as the main source of irrigation due to climate change, changes in land use and other uses such as domestic needs. Therefore, the complexity and limitations of the water resource are a challenge for irrigation development now and in the future. This research intends to optimize the irrigation water allocation by suing the dynamics system. By analyzing the causal relationships that affect the water availability, causal relationships that affect water demand, and formulating interventions with high leverage, the optimal condition is found. The results show that the limited amount of water availability with the increasing number of waters needs for various uses requires arranging the optimal water allocation in a fair, efficient and environmentally sound sense. However, the use of water for irrigation that can be allocated to fisheries will obtain maximum economic benefits if fisheries

Keywords: dynamics system model, irrigation, water allocation, optimization.

灌水量优化配置的动力学系统模型

摘要：本文拟构建灌 水量优化配置。该研究方法使用动态系统，该方法包括构建放大（正反馈回路）或否定（负反馈回路）系统变量变化的因果回路图。水平衡是水资源的一个重要方面。它的存在可以提供特定时期内水资源可用性和水需求之间的平衡表状况的概览。水平衡表可以显示可用水的状况，是已经亏空还是仍然过剩。水资源管理的一部分由动态的社会系统决定,取决于环境条件,主要是因为不同行政区域和不同文化的参与者、用途的多样性。由于气候变化、土地利用变化和其他用途（如家庭需求),可通过水源灌发的方法主要来源减

少，进一步加剧了这种情况。因此，水资源的复杂性和局限性是当前和未来灌发发展面临的挑战。本研究旨在利用动力学系统优化灌发水量分配。通过分析影响可用水量的因果关系、影响需水量的因果关系，制定高杠杆的干预措施，找到最优条件。结果表明，随着各种用途对水的需求不断增加，可用水量有限，需要以公平、高效和无害环境的方式安排最佳水资源分配。但是，如果渔业在水量分配中处于优先地位，可分配给渔业的灌发用水将获得最大的经济效益.

关键词：动力系统模型，灌溉，水资源分配，优化.

1. Introduction

Irrigation as part of the water resource management is a system in society that is dynamic and depends on the environmental conditions, mainly because of the variety of actors, the variety of uses, across the different administrative areas and the different cultures. This condition is further aggravated by the reduction in water sources that can be used as the main source of irrigation [1-3] due to of climate change, changes in land use and other uses such as domestic needs. Therefore, the complexity and limitations of the water resource are a challenge for irrigation development now and in the future [4, 5].

Water management is a controversial environmental policy issue, due to the heterogeneity of interests that is associated with shared resources and the increasing level of conflict between the water use and other users. Currently, there is a cumulative interest in improving multi-stakeholder decision-making processes, overtaking the binding trade business, in the water management domain. This requires the development of dynamic decision aids capable of integrating the various problem frameworks that is held by the decision-makers, to clarify differences, to support the creation of collaborative decision-making processes and to provide a platform for shared interaction [6, 7]. Optimal irrigation water management in an infrastructure will be able to irrigate more rice fields [8, 9], as well as more water left for other water users, including households, urban and industry, plantations, fisheries, and the environment and does not even rule out the possibility of developing agricultural products to improve the welfare of farmers.

The purpose of making this paper is to determine the current water allocation with the conditions of the weir and the availability of existing water, and to find the optimal water allocation by using a dynamics system model.

2. Material and Method

2.1. Dynamics System

Forrester [10] states that Dynamics system is a theory about the structure of a system and a collection of tools for presenting the complex systems and analyzing the dynamic behavior. An important benefit of this approach is to explain the structure of the system, to see how the elements of the system are interrelated, and to try changing the various relationships if a decision is included. In Dynamics system, the link between structure and behavior is based on the concepts of information feedback and control [11]. Furthermore, the causal loop diagrams state a feedback mechanism, which amplifies (positive feedback loop) or negates (negative feedback loop) for a change in a system variable [12].

The relationship between systems thinking and the Dynamics system is emphasized by Caulfield and Maj [12] the system is a tool to help think systemically by using graphic devices to describe systems. The causal loop diagram method used in Dynamics system since the 1970s can be used for discussion, and development of computer models.

2.2. Dynamics System Modeling

The basis of the Dynamics system methodology is systems analysis. A system (can consist of several sub-systems) is defined as a set of elements that interact with each other with interaction patterns that influence each other and determine each other. Problems that have a dynamic nature and have a feedback structure will be appropriate if a modeling approach is carried out using Dynamics system.

In the Dynamics system paradigm, it is assumed that the real world is a system that has a feedback structure with linear and non-linear relationships and in which there is a time delay. A decision taken and applied to a system will change in the system. These changes in circumstances can occur at any stage where a decision has been made. Therefore, the situation at one stage will be related to the situation at another stage or in other words, a decision will influence each other between stages.

A collection of optimal decisions at each stage will form an optimal decision for all stages. The phasing for a complex problem will make it easier to solve the problem because the dynamic program has been designed for this purpose. Dynamic programming provides a solution technique that requires much less effort than trial and error solutions. With dynamic programming, a complex and large-scale problem can be solved by dividing it into several small parts, which are then optimized, this method is known as the decomposition technique.

2.3. Dynamics System Simulation Tool

Prodnovic & Simonovic [13] suggested that the dynamics system approach, which states the system structure as a diagram, can be used to communicate with other parties, and seek high-leverage interventions to solve problems. The tools of this approach are: causal loops, behavior over time graphs, stock and flow diagrams, systems archetypes), and simulation program (DSS generator): Dynamo, Powersim, Vensim, Stella, Madonna, which is object-oriented programming (object-oriented program). The simulation program is equipped with a graphical facility to express the structure of the system in a simple form, easy to understand, and can be used to solve water resource management problems that full non-linear relationships.

The dynamics system consists of: stock, flow, converter, and connector, as seen in Figure 1. Stock states how the condition and accumulation of resources, for example to state the increase in population, the area of irrigated land. Flow expresses the action of how something happens, which is measured as a rate. Converters are used to accommodate inputs, and create outputs. The connector states the relationship between the stock and the flow with the converter.

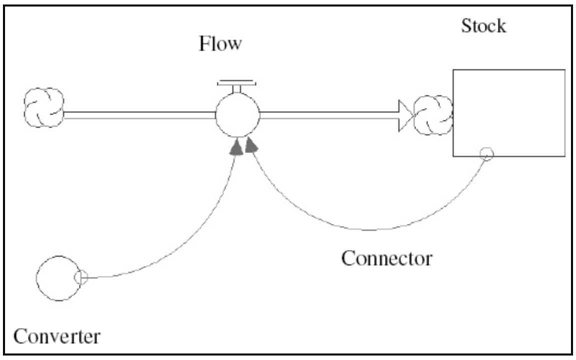

Fig. 1 Dynamics system model

3. Methodology

The following is the design of the sequence of research implementation as follows:

1. Identification of Conditions and Dynamics of Resource usage
   a) Collection of information, data, maps, legislation
   b) Data elaboration and analysis of model input variable preparation
2. Arrangement of block models
   a) Drawing up a causal diagram (CLD)
   b) Prepare effective and efficient strategic intervention efforts
3. Transformation to Computer Model
   a) Develop scenarios (with and without sysdyn)
   b) Determination of level, rate
4. Dynamics system Computer Simulation
   a) Running Model
   b) Result Analysis: Calibration & Verification of results
   c) Input correction and re-iteration
5. Reporting
   a) Conclusion
   b) Recommendations

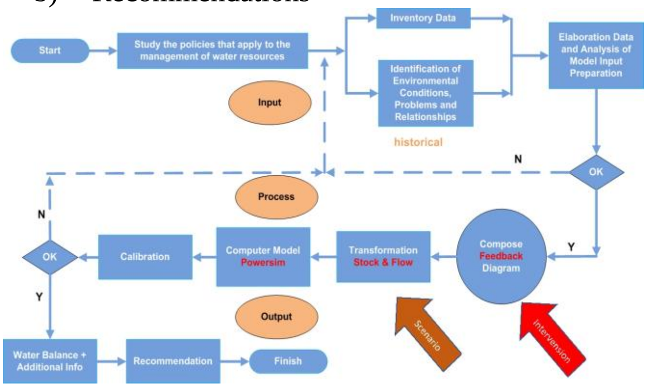

Fig. 2 Methodology of dynamics system modeling

4. Results and Discussion

4.1. Causal Loop Diagram

Causal Loop diagram describes the cause and effect of a variable in a unified system. The effect of one variable on other variables can be 1) positive or strengthen or enlarge, and 2) negative or weaken or reduce.

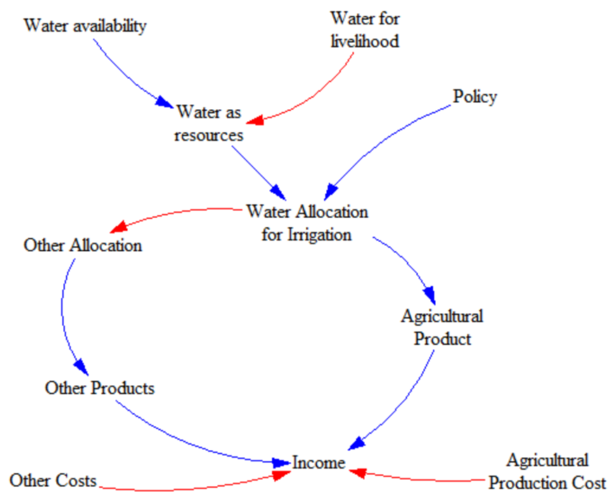

Fig. 3 Causal loop diagram

The following figure shows a causal diagram of the water allocation policy of how much allocation is given to rice field irrigation. The explanation is as follows.

1. In accordance with the mandate of Law 17/2019 concerning Water Resources, it is necessary to fulfill the need for water for the maintenance of water sources and the environment.
2. After deducting the need for environmental water, water can be obtained that can be used as a

resource, namely for irrigation of rice fields and others (e.g. inland fisheries).

3. water allocation policy determines how much water is allocated for irrigation and fisheries.

4. Water allocated to irrigation will reduce allocation for fisheries

5. Water allocation for irrigation increases rice production

6. Water allocation to fisheries increases fish production

7. Total income is the rupiah value of rice production plus the value of fish production, and is reduced by production costs

8. This income increases cumulatively over time.

4.2. Model Structure

Based on the causal loop diagram, the structure of the model is structured as follows.

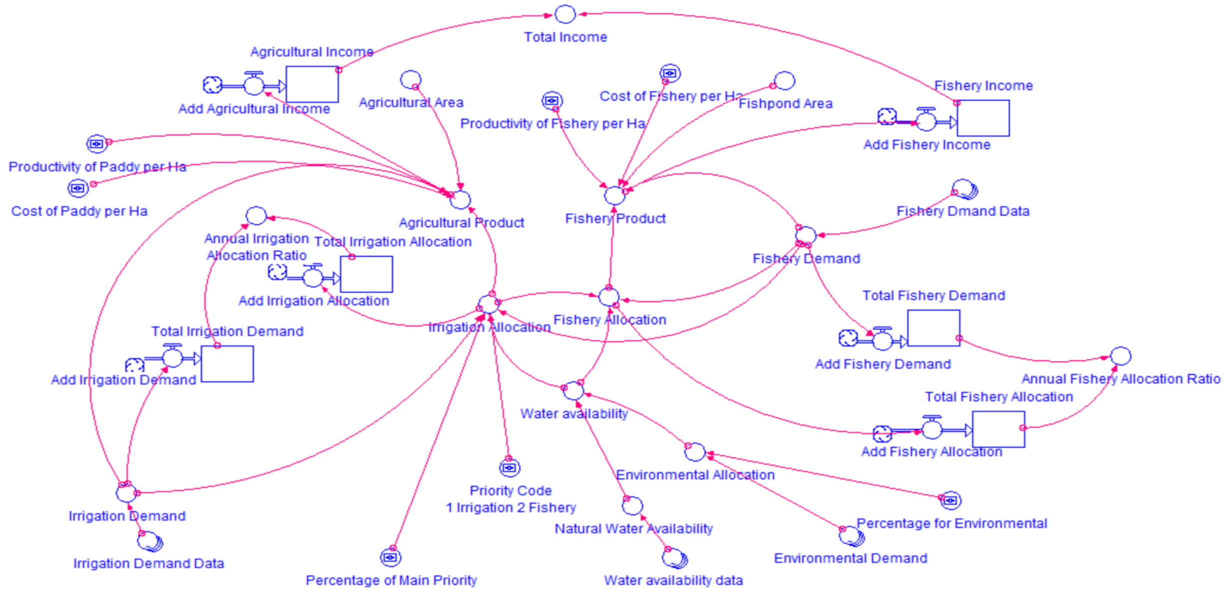

Fig. 4 Layer model of Stella's dynamics system program

Principally, the program conducts calculations by reading water availability, irrigation water needs, fishery water needs, and water needs for river maintenance. The policy is used as a reference in determining how the priority of water allocation is applied, namely, through the Priority Code, which has a value of 1 for agriculture priority, and 2 for fisheries priority.

Water for the main (first) priority can be allocated according to its needs, or limited to a percentage that can be included as input in the Percentage of the Main Priority Allocation. The water for the next priority gets the remaining water from the user with the top priority. The production is assumed to be linearly proportional to the fulfillment of water needs, which is directly proportional to the K-factor = supply/need.

Total income is the sum of income from agriculture and fishery income. Agricultural income and fishery income are the sum of their respective net production. The net production is the production per hectare minus the cost per hectare and multiplied by the area of the rice field or fish pond concerned.

The conditions for meeting global water needs in a year are presented in the graph at the bottom of the Layer Interface. The water allocation policy whether priority on irrigation or fisheries, is entered via the slider button on the Interface Screen. In accordance with Law 11/2019 concerning Water Resources, it is necessary to consider the need for water for the maintenance of water sources and the environment. In this model, the environment always has top priority, but can be assigned from 0% to 100% via the slider button.

The allocation percentage for water users with top priority (first) can also be changed with the slider button on the Interface Screen. Generally, the allocation percentage is filled with 1 or 100%. However, to achieve justice can be reduced by shifting to the left.

By doing the RUN many times by observing the percentage of irrigation, fisheries and the environment fulfilled in the bottom graph, and checking the Income at the bottom right, it will get a fair water allocation, giving maximum economic value and being environmentally friendly according to the criteria for Integrated Water Resources Management or IWRM, which is 3E: equity, economic efficiency, and environmental sustainability. Figure 5 presents the Layer Interface on the Stella Model, for entering data and observing results.

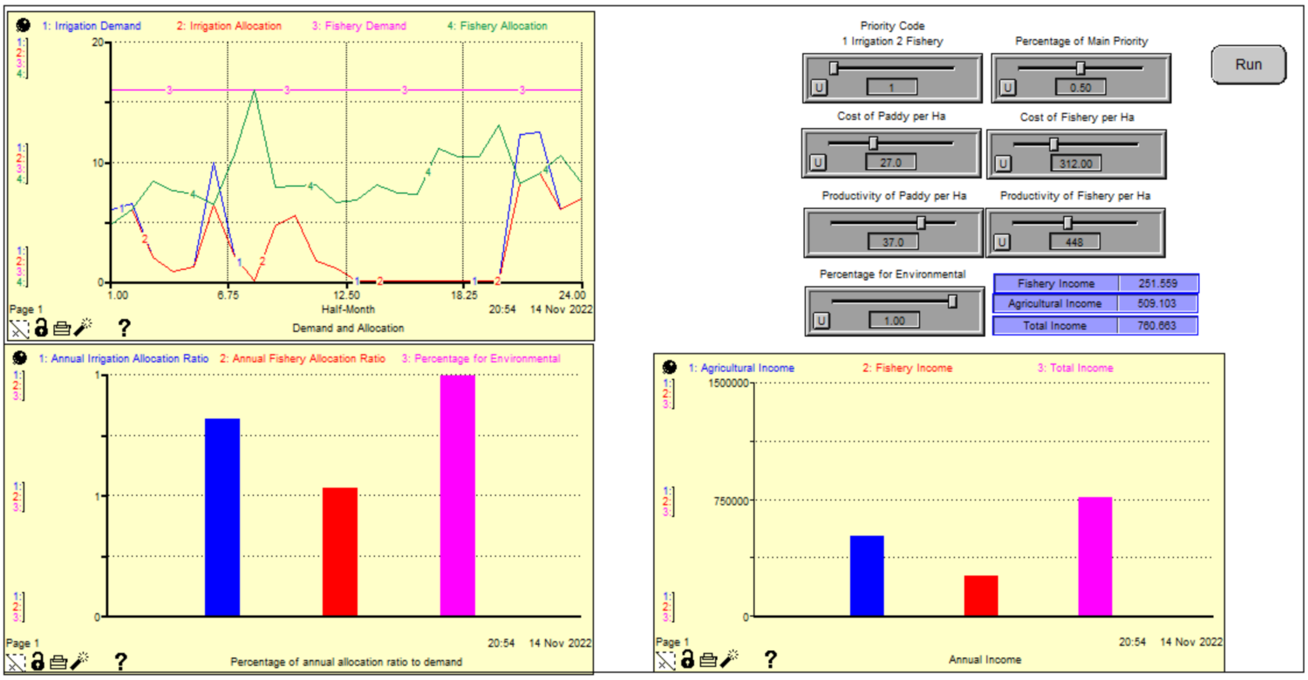

Fig. 5 Layer interface on the Stella model, for entering data and observing results

4.3. Production Value and Cost

Data from the Central Statistics Agency [14] state that rice plants for each growing season will produce an average production of Rp. 18,514,840.00. While the production cost is Rp. 13. 559.300.00If in a year there are two planting seasons, then in a year the production cost will be the around 27 million Rupiah, and the production will be the around 37 million Rupiah. If there is a shortage of irrigation water, it is assumed that rice production will decrease linearly.

For the fishery production, namely tilapia, based on data from the Ministry of Maritime Affairs and Fisheries [15], the production cost per hectare is around 312 million Rupiah per year, while the production value per year is 448 million Rupiah.

4.4 Optimization Results

The results of the run for the existing conditions, namely the priority on irrigation with a percentage of 100% have resulted in meeting the water requirements for maximum irrigation, the rest for fish ponds after deducting 5% of the existing water environment (total net income 998 million). Table 1 and Figure 1 present the priority for agriculture with the percentage of 100%.

4.4.1. Priority for Fully Irrigation (100%)

The conditions for fully irrigation (100%) are presented in Figure 6 and 7, and Table 1.

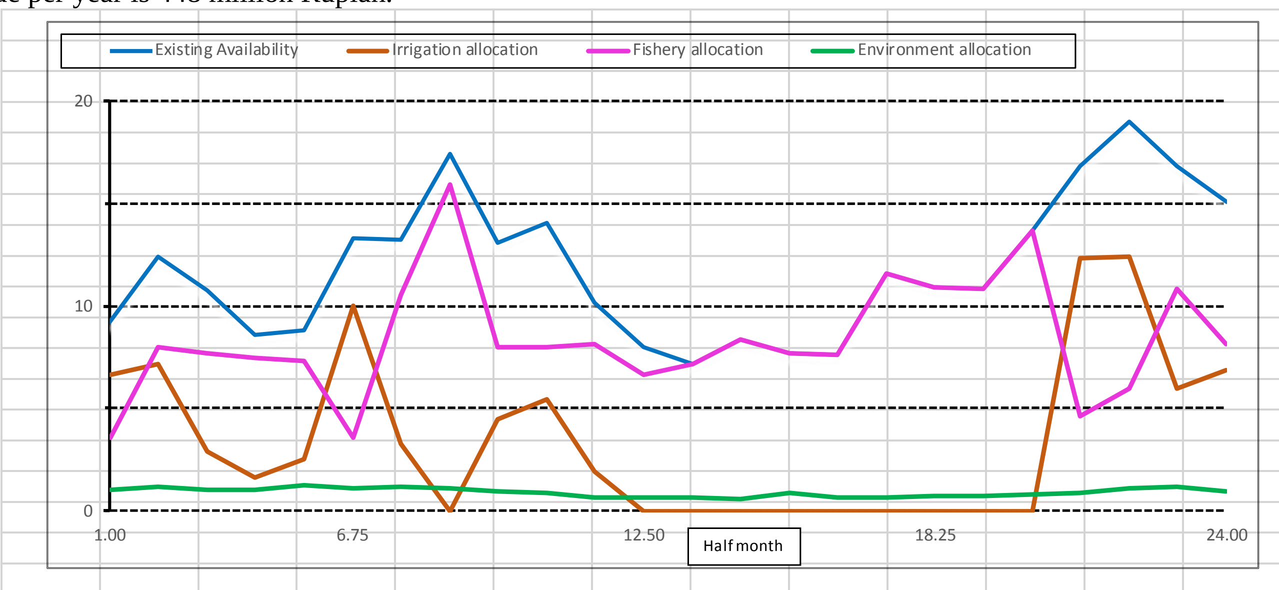

Fig. 6 Layer interface on the Stella model, for entering data and observing results

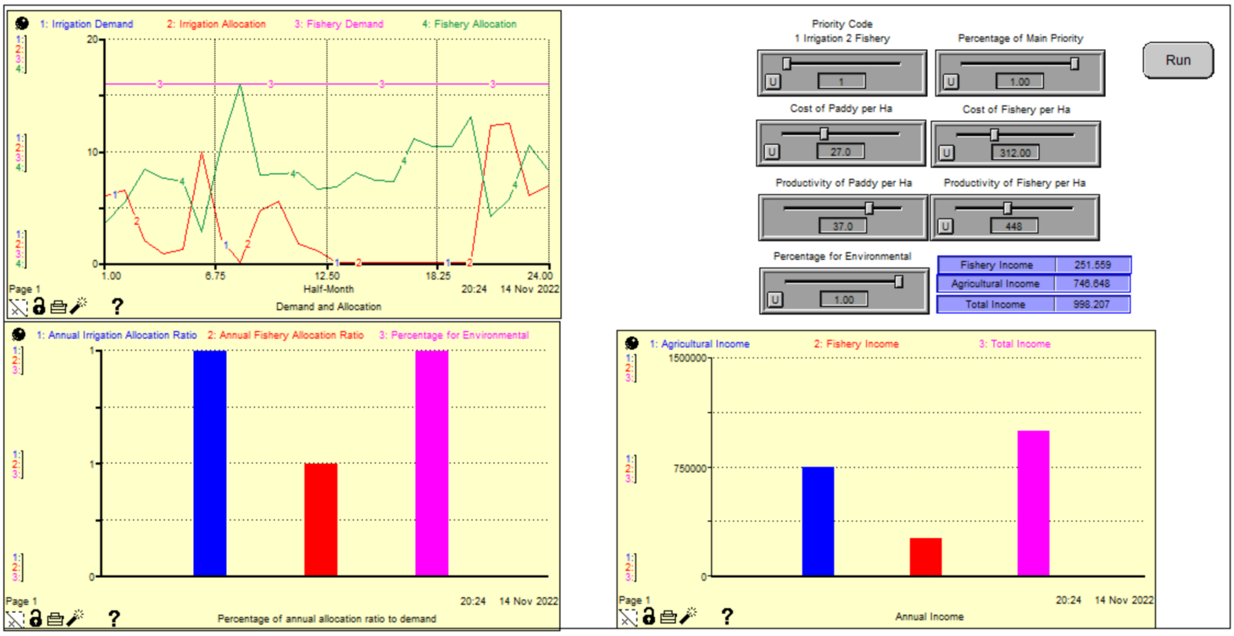

Fig. 7 Water availability and allocation for the priority on fully irrigation (100%)

Table 1 Water availability and allocation for priority on fully irrigation

Half-month	Existing Availability	Irrigation need	Irrigation allocation	Fishery need	Fishery allocation	Environment need	Environment allocation
1	10.10	5.99	5.99	15.94	3.61	0.50	0.50
2	12.43	6.43	6.43	15.94	5.38	0.62	0.62
3	10.73	1.89	1.89	15.94	8.30	0.54	0.54
4	8.61	0.69	0.69	15.94	7.49	0.43	0.43
5	8.79	1.10	1.10	15.94	7.25	0.44	0.44
6	13.32	9.90	9.90	15.94	2.75	0.67	0.67
7	13.23	2.02	2.02	15.94	10.55	0.66	0.66
8	17.45	0.00	0.00	15.94	15.94	0.87	0.87
9	13.12	4.60	4.60	15.94	7.86	0.66	0.66
10	14.10	5.49	5.49	15.94	7.90	0.71	0.71
11	10.18	1.64	1.64	15.94	8.03	0.51	0.51
12	8.02	1.07	1.07	15.94	6.55	0.40	0.40
13	7.14	0.00	0.00	15.94	6.78	0.36	0.36
14	8.39	0.00	0.00	15.94	7.97	0.42	0.42
15	7.66	0.00	0.00	15.94	7.28	0.38	0.38
16	7.60	0.00	0.00	15.94	7.22	0.38	0.38
17	11.62	0.00	0.00	15.94	11.04	0.58	0.58
18	10.91	0.00	0.00	15.94	10.36	0.55	0.55
19	10.86	0.00	0.00	15.94	10.32	0.54	0.54
20	13.68	0.00	0.00	15.94	13.00	0.68	0.68
21	17.16	12.23	12.23	15.94	4.07	0.86	0.86
22	19.01	12.42	12.42	15.94	5.64	0.95	0.95
23	17.30	5.99	5.99	15.94	10.45	0.86	0.86
Final	15.94	6.87	6.87	15.94	8.27	0.80	0.80

4.4.2. Priority for Fully Fishery (100%)

While the results of the run for priority in fisheries with a percentage of 100% have resulted in the fulfillment of maximum water requirements for fisheries, the rest is for irrigation after deducting 5% of the existing water environment. Total revenue 1,068 million. Figure 8 and 9, and Table 2 present the priority for fully fishery (100%).

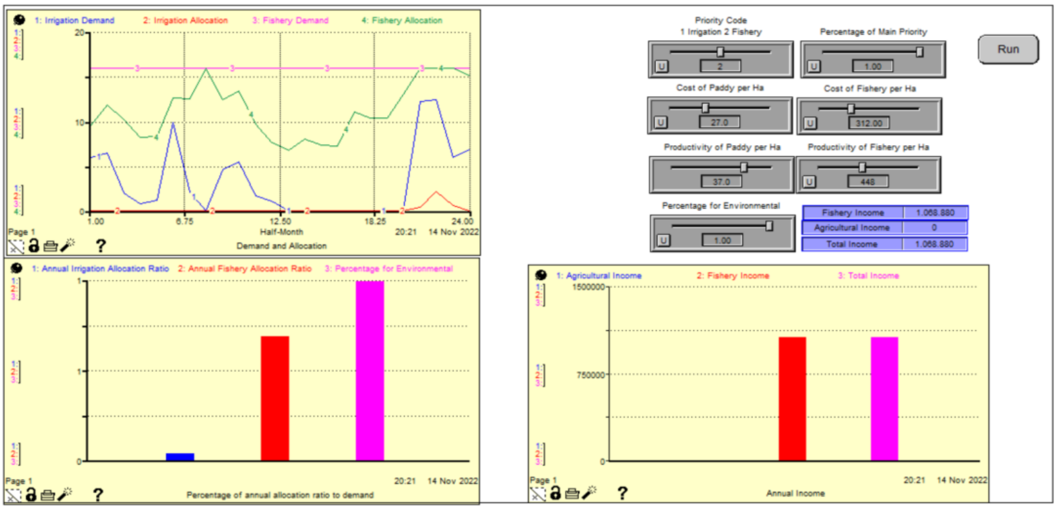

Fig. 8 Priority for fisheries with a percentage of 100%

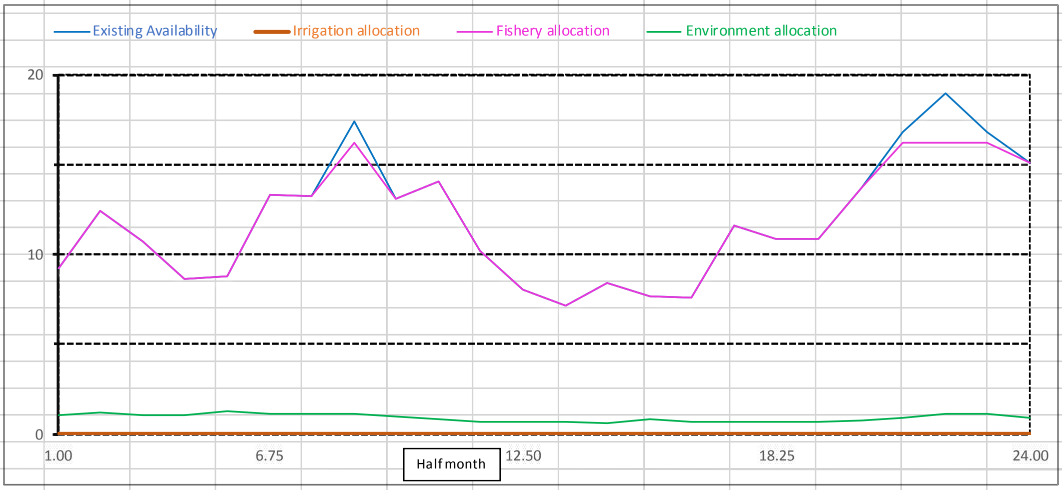

Fig. 9 Availability and allocation of water for priority in fully fisheries (100%)

Table 2 Availability of water and allocation of water for priority in fisheries fully

Half-month	Existing Availability	Irrigation need	Irrigation allocation	Fishery need	Fishery allocation	Environment need	Environment allocation
1.00	9.25	5.99	0.00	15.94	9.25	0.50	1.05
	12.43	6.43	0.00	15.94	12.43	0.62	1.20
	10.73	1.89	0.00	15.94	10.73	0.54	1.05
	8.61	0.69	0.00	15.94	8.61	0.43	1.05
	8.79	1.1	0.00	15.94	8.79	0.44	1.25
6.75	13.32	9.9	0.00	15.94	13.32	0.67	1.10
	13.23	2.02	0.00	15.94	13.23	0.66	1.15
	17.45	0	0.00	15.94	16.26	0.87	1.10
	13.12	4.6	0.00	15.94	13.12	0.66	0.95
	14.1	5.49	0.00	15.94	14.1	0.71	0.85
	10.18	1.64	0.00	15.94	10.18	0.51	0.65
12.50	8.02	1.07	0.00	15.94	8.02	0.40	0.65
	7.14	0	0.00	15.94	7.14	0.36	0.65
	8.39	0	0.00	15.94	8.39	0.42	0.60
	7.66	0	0.00	15.94	7.66	0.38	0.85
	7.6	0	0.00	15.94	7.6	0.38	0.65
	11.62	0	0.00	15.94	11.62	0.58	0.65
18.25	10.91	0	0.00	15.94	10.91	0.55	0.70
	10.86	0	0.00	15.94	10.86	0.54	0.72
	13.68	0	0.00	15.94	13.68	0.68	0.78
	16.85	12.23	0.00	15.94	16.20	0.86	0.90
	19.01	12.42	0.00	15.94	16.20	0.95	1.10
	16.85	5.99	0.00	15.94	16.20	0.86	1.13
Final	15.14	6.87	0.00	15.94	15.10	0.80	0.94

4.4.3. Priority of Half Fishery (50%)

The results of the run for priority in fisheries with a percentage of 50% have resulted in the fulfillment of water needed for optimal irrigation, the rest for fish ponds after being reduced by 5% of the existing water (total revenue 558 million). Table 3 is a tabulation of the results of the three run models carried out. Figure 10, 11 and Table 4 present the priority of the half fishery (50%).

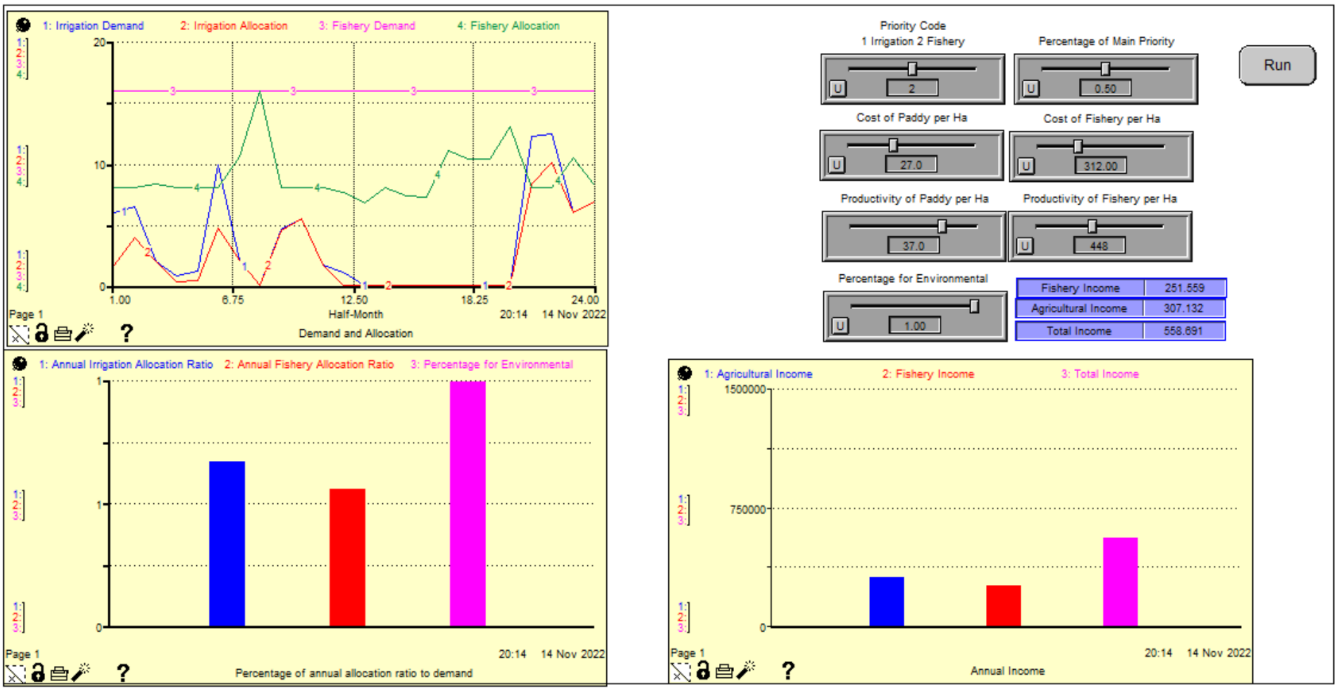

Fig. 10 Priority for fisheries with a percentage of 50%

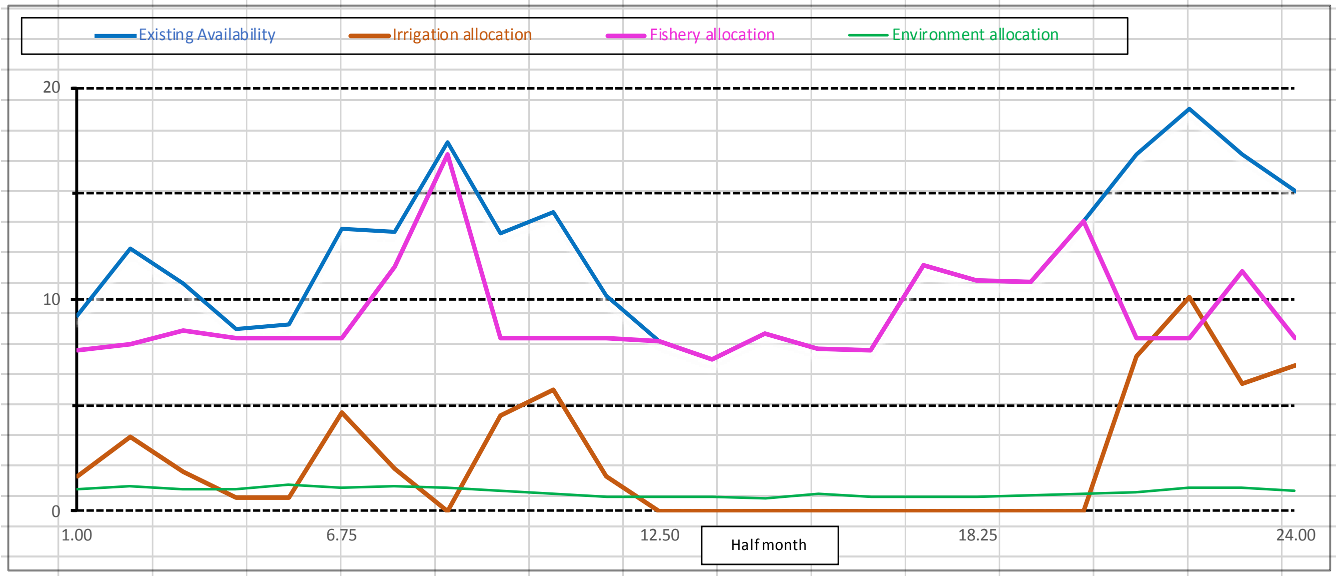

Fig. 11 Water availability and water allocation for priority in fisheries with the percentage of 50%

Table 3 The summary of water allocation optimization results

Priority of water allocation	**Top priority percentage**	**Fulfillment of water needs**			**Income**		
		Agriculture	**Fishery**	**Environment**	**Agriculture**	**Fishery**	**Total**
Irigasi	100%	100%	53%	100%	746	251	998
Perikanan	100%	7%	100%	100%	0	1.068	1.068
Perikanan	50%	57%	58%	100%	307	251	558

Table 4 Water availability and water allocation for priority in fisheries with the percentage of 50%

Half-month	Existing Availability	Irrigation need	Irrigation allocation	Fishery need	Fishery allocation	Environment need	Environment allocation
1.00	9.25	5.99	1.63	15.94	7.6	0.50	1.05
	12.43	6.43	3.54	15.94	7.9	0.62	1.20
	10.73	1.89	1.89	15.94	8.5	0.54	1.05
	8.61	0.69	0.60	15.94	8.18	0.43	1.05
	8.79	1.10	0.65	15.94	8.18	0.44	1.25
6.75	13.32	9.90	4.68	15.94	8.17	0.67	1.10
	13.23	2.02	2.02	15.94	11.57	0.66	1.15
	17.45	0.00	0	15.94	16.84	0.87	1.10
	13.12	4.60	4.49	15.94	8.18	0.66	0.95
	14.1	5.49	5.72	15.94	8.18	0.71	0.85
	10.18	1.64	1.64	15.94	8.16	0.51	0.65
12.50	8.02	1.07	0	15.94	8.02	0.40	0.65
	7.14	0.00	0	15.94	7.14	0.36	0.65
	8.39	0.00	0	15.94	8.39	0.42	0.60
	7.66	0.00	0	15.94	7.66	0.38	0.85
	7.6	0.00	0	15.94	7.6	0.38	0.65
	11.62	0.00	0	15.94	11.62	0.58	0.65
18.25	10.91	0.00	0	15.94	10.91	0.55	0.70
	10.86	0.00	0	15.94	10.86	0.54	0.72
	13.68	0.00	0	15.94	13.68	0.68	0.78
	16.85	12.23	7.33	15.94	8.16	0.86	0.90
	19.01	12.42	10.09	15.94	8.15	0.95	1.10
	16.85	5.99	5.99	15.94	11.3	0.86	1.13
Final	15.14	6.87	6.87	15.94	8.14	0.80	0.94

5. Conclusion

From the research on Dynamic System Models for Optimizing Irrigation Water Allocation with Case Study: Rao Irrigation Area, Pasaman Regency, West Sumatra Province, it can be concluded several things as follows:

1. The limited amount of water available while the increasing amount of water needed for various uses requires us to arrange optimal water allocation in a fair, efficient and environmentally sound sense.
2. The dynamic system model can be used as a tool to determine the optimal water allocation.
3. From the case of Panti Rao, the benefits that are obtained from fishing are countless, which is dominating the benefits of irrigation, so that the amount of net income that is obtained will occur if the fisheries are given top priority. Of course, it has the potency to disrupt the rice food security, so the arrangements are needed to limit the proliferation of fishery businesses.

5.1. Recommendations

Due to the dynamics system shows that the limited amount of water availability and the increasing amount of water needed for various uses requires arranging the optimal water allocation in a fair, efficient and environmentally sound sense. From this research, several recommendations can be made, as follows:

1) The use of water for irrigation that can be allocated to fisheries will obtain maximum economic benefits if fisheries get top priority in water allocation.

2) The use of irrigation water for fisheries will become increasingly widespread because it will provide higher financial benefits than growing rice. This requires regulation so that food security, especially rice, can be maintained.

3) Further research needs to be done by incorporating elements of rice self-sufficiency at the regional level and its contribution at the national level, so that the dynamic system model will be able to provide an optimal solution that maximizes financial and economic benefits without compromising rice self-sufficiency.

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