HYBRID WATER INPUT-OUTPUT MODEL FOR REGIONAL MANAGEMENT

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***ABSTRACT*:** This paper shows the application of mixed-unit input-output model in regional water accounting. The main advantage of this model consists in being able to replace non-homogeneous flows of goods and services with significant variations in average prices of water among the different purchasers by the volume of required water in the traditional input-output analysis. In this paper, the hybrid system is constructed using various data sources such as inter-regional input-output table of Yoshino River Basin, Japan, and water use account in each industrial sector, including in household purpose. Water demand of each product is analyzed using the mixed Leontief inverse. The calculation results show that agricultural products are responsible as majority of the total water used in Japan's economy. This current study demonstrates a combination of tools and techniques that are developed in the fields of water resources engineering and input-output economics in addressing major water policy imperatives. The results are expected to inform the water policy makers in prioritizing major areas needed to understand the water impact of the regional economy.

KEYWORDS: Hybrid input-output model, Water, Regional management.

1. INTRODUCTION

Water is essential for life. Nowadays, there is increasing competition for water use in growing food, generating electricity, producing many manufacturing products including goods and services, as well as in maintaining the suitable ecosystem functions. This competition has become as pressure on the water resources system for example many regions are experiencing water shortage and its economic damage. This causes regional policy makers to integrate economic and environmental issues in order to make better decisions in integrated water resources management to meet demands of socio-economic development.

Based on the above essential issues, United Nations (UN) has prepared and developed the System of Environmental-Economic Accounting for Water (SEEA-Water) since 2003 to provide a challenging opportunity to develop methodologies for water account. In 2012, UN reported a new version of the System of Environmental-Economic Accounting for Water (SEEA-Water), describing the interaction between the economy and the environment [United Nations, 2012]. The objective of development of SEEA-Water is to provide a standard of concepts and methods for water accounting. The United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA) also recommended SEEA-Water to use this SEEA-WATER as an international standard.

One of the important issues in SEEA-WATER presented by UN is how to describe the economy of water by presenting a combination of national accounts with physical information on water uses [United Nations, 2012]. This integrated national account can be referred to as hybrid accounts which represent to the combination of different types of unit of measurement in the same accounts. Using this hybrid account enables policy makers to evaluate the impact on water resources of changes in the economy.

Hybrid accounts can be classified by two types: 1. the supply and use tables, and 2. the input-output table (IOT) (for details, please see [United Nations, 2012]). However, this paper centers only the hybrid input-output table because of data availability.

The hybrid IOT has been widely applied in engineering fields especially for energy. Chung et al. (2009) estimated energy consumption and GHG emission to meet the demand of economic development in Korea. Federal Statistical Office of Germany (2011) illustrated a case study of extended IOT for energy and greenhouse gases in Germany. Chung et al. (2011) discussed the use of hybrid IOT to evaluate the direct and indirect consequences Korean energy policies. Chik at al. (2012) showed an application of hybrid IOT to identify the source of change in the energy intensity.

However, there is little experience in the use of IOT for water resources engineering for a number of reason. For example, the IOT is economic approaches which centers on the administrative level such as national, regional, prefectural, or city but water resources is managed by the river basin basis in which the regional breakdown is generally different. The data for analysis are not accessible especially water use to meet demand of each industrial product.

The objective of this paper is to develop hybrid input-output table for water management in regional level. This proposed water hybrid IOT can enable a more complete assessment of water use in physical unit to meet the demand of production in monetary term. The case study was selected from Yoshino river basin in Shikoku region, Japan.

2. METHODOLOGY

2.1 Traditional input-output analysis model

Input-output analysis (IOA) is an analytical framework developed by Professor Wassily Leontief who received the Nobel Prize in Economic Science in 1973 (Nobelprize, 1973). The main feature of IOA is to analyze the interdependence of industries in an economy. An input-output model consists of a system of linear equations, describing the distribution of an industry's product throughout the economy.

Miller and Blair (2009) described IOT as the flows of products from each industrial sector, considered as a producer, to each of the sectors itself and others, considered as consumers. The rows of this table describe the distribution of a producer's output to each consumer such as (1) the other industries that use this output for the production process, and (2) the final demand groups that consume this output including household, government, exports. The columns describe the composition of input required by a particular industry to produce its output such as the raw materials, products from the other industries, labor, and natural resources. Water is also one of the essential resources for economic development.

A main application of IOA is to assign production factors to the final demand of goods and services. For example, it is used to calculate how much water in the whole national economy is required to meet the additional production of textile industry to support the world market. In this model, an integration of the direct water use in textile production and the indirect water consumed by all suppliers of textile product is defined as the whole water use for this textile industry. This means additional textile goods and activities for the world market are considered as final demand.

Based on the above example, the assignment of production factors (water) to final demand (additional textile products) can be calculated by using Leontief inverse by multiplying the Leontief inverse matrix with the matrix of the final demand. However, the water used in this case is illustrated in monetary term which cannot represent the free water in agricultural purpose. To address this shortcoming, water use coefficient to those output values can enable the linkage of water use of the final demand category to be calculated.

The process of IOA to calculate water use is as follow. First, vector of output is formulated from the sum of intermediate transaction and final demand into Eq. (1). Then, Eq. (1) is transformed into the matrix format as Eq. (2). Next, Eq. (3) is illustrated with the basic equation for IOA with Leontief inverse matrix. Finally, water requirement in producing final demand is calculated by linking a water use unit coefficient with the output as shown in Eq. (4) (for detail, see [Miller. and Blair., 2009]). Fig.1 also shows a schematic diagram of how to use traditional IOA in the calculation of required water of final demand.

$$x = A * x + f \tag{1}$$

$$X - AX = F \tag{2}$$

$$X = (I - A)^{-1} * F \tag{3}$$

$$W = w * L * F \tag{4}$$

where x = vector of output, f = vector of final demand, A = matrix of input coefficient, I = identity matrix, L = Leontief inverse matrix $(I-A)^{-1}$, w = water use unit coefficient, W = total water use in producing final demand goods and services.

2.2 Hybrid water IO model

The IOA model can be developed not only in monetary term, but also in combination of both monetary and physical flows.

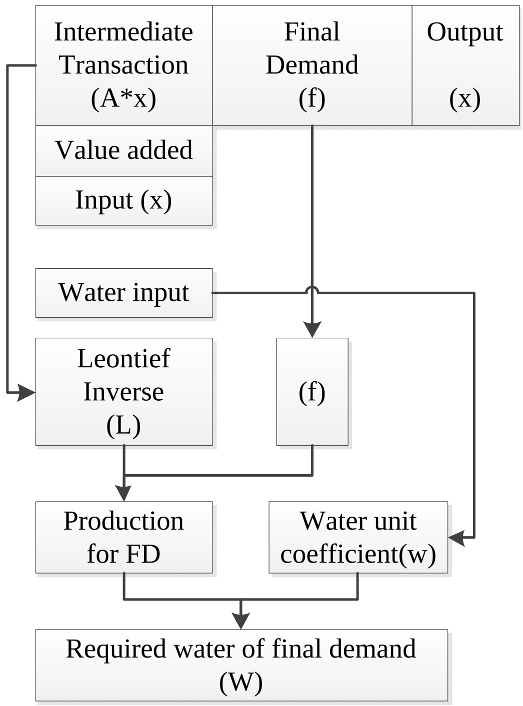


Fig. 1. Schematic diagram of calculation of water demand for goods and services.

In case of hybrid water IO model, the line of the use of water is replaced by the physical-unit details such as million cubic meters. The final demand and output are partly presented by values and volumes.

The most important advantage of hybrid water IOT compared with the traditional IOT with only monetary unit is that non-homogeneous flows of goods and services with a wide variety in average prices among the different purchases are replaced by the water volume. For example, only water which is paid by users is entered into the traditional IOT. This causes misunderstanding for policy makers to evaluate water requirement to meet the economic development. This is because free water used in agricultural sector which is generally the majority of total water use is not accounted into traditional IOT. This hybrid IOT contributes to a significant improvement in the result quality compared with the traditional one.

The calculation of the mixed Leontief inverse in Hybrid water IOA is the same as in the case of the traditional IOA. However, some parts of the traditional IOT have to be replaced for becoming into mixed IOT. The process of hybrid water IOA is as follow. First, the mixed IOT is formulated with both monetary and physical units. Then, the input coefficients and mixed Leontief inverse coefficients are determined. Next, the indirect output to produce the assigned final demand goods and services are calculated. The specific water input of the branches (primary water coefficients) based on the water account is generated. Finally, the required water content by final demand goods and services is calculated. The calculation flow of hybrid water input-output analysis can be seen in Fig. 2.

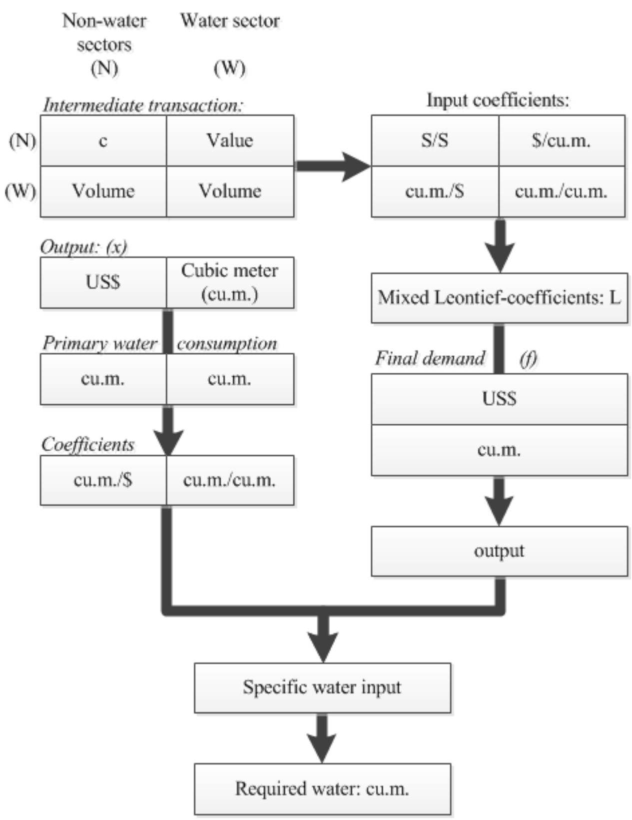


Fig. 2. Hybrid water input-output analysis

2.3 Water problems in Yoshino River Basin

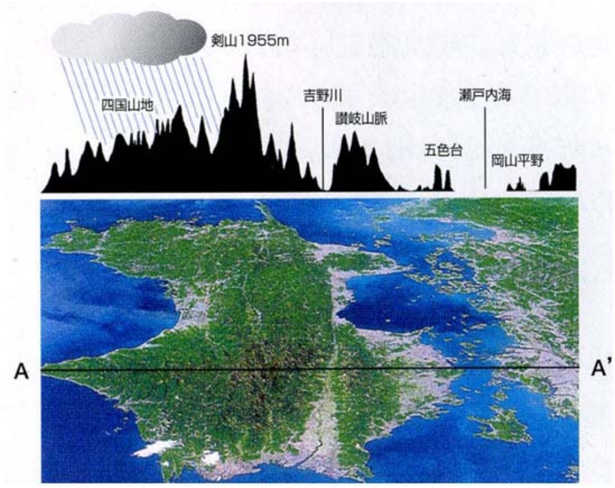
Yoshino River Basin is known as one of the complex area in Japan for regional water management. This is based on (1) the complexity of inter- and intra-regional water sharing, and (2) the huge difference of rainfall pattern inside and outside basin resulting to flood and drought in Shikoku region. Yoshino is a major river basin located in the Shikoku Island, the southern part of Japan. It is 194 km long with a watershed of 3,750 km^2.

Yoshino river basin is an interregional river system and its water resources are shared by all four prefectures in Shikoku region: Kochi, Ehime, Kagawa, and Tokushima prefectures as shown in Fig. 3. The majority of water resources is distributed within river basin itself from the upstream in Kochi prefecture to the downstream in Tokushima prefecture. However, some part of water is shared to some cities of all four prefectures which are located outside this basin. In drought years, this water supply system leads to the conflict between the stakeholders of up- and downstream or between the users in- and outside the basin.

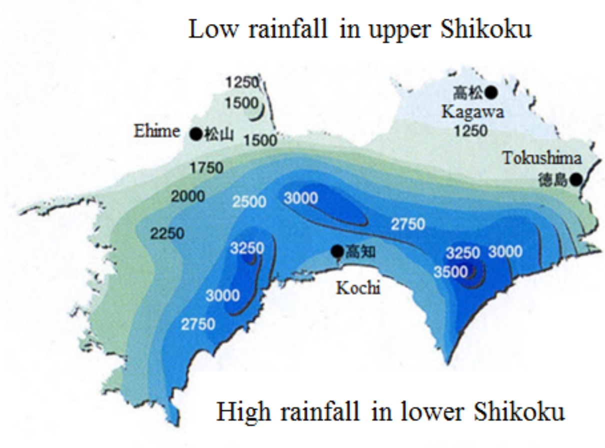
Fig. 3. Yoshino River Basin

(Source: http://www.water.go.jp/honsya/honsya/english/jwa_ta/map5.html)

Another complex issue of Yoshino river basin is the difference of rainfall between the upper and lower parts of Shikoku Island. According to the geographical condition of Shikoku region as the mountain in the center of island, there are two main rainfall patterns over this area as shown in Fig. 4.



(a) Physical condition



(b) Rainfall pattern

Fig. 4. Physical condition and rainfall pattern of Yoshino river basin in Shikoku region

(Source: www.mlit.go.jp)

First, the lower region combining the Kochi and Tokushima prefectures receives a large amount of annual rainfall. The Sameura dam, which is the biggest dam in this river system, is also located in the Kochi prefecture (the lower region). Second, the upper region including the Ehime and Kagawa prefectures receives less rainfall, only 30% of the lower region. However, this upper region can produce approximately 60% GDP of the Shikoku region. According to precipitation conditions, the water problems in this Yoshino river basin are not only flood in the lower part, but also drought in the upper area.

Ministry of Land, Infrastructure, Transport and Tourism (MLIT) declared the Yoshino River Basin as one of the severe water shortage area in Japan (MLIT, 2013). The people in this area always experience not only flash flood caused by typhoons, but also water shortages resulting from limited supply almost every two or three years. They require a suitable water management system which can enable the policy makers balance the water demand and supply under uncertainty of changing climate and economic development.

2.4 Water resources management in Yoshino river basin

There are two main topics in water resources management: water supply and water demand. Water supply which is operated by dam system in this basin can be seen in Fig. 5. Sameura dam, the biggest multi-purpose dam in this basin, is the main part to control, distribute, and manage water supply for the whole basin; however, its capacity is only 320 million cubic meter. In fact, it can be inferred that this dam is being operated for only one-year period based on the limitation of its capacity. Another main problem from this capacity is that the uncertainty of huge inflow caused by typhoon. Typhoon sometimes approaches this area in September and October for 2-3 times per year. For instance, in August of year 2013, there was only 30 % of water capacity in this dam; however, there were a number of typhoons approaching this area during September and October 2013. After this situation, Sameura dam's capacity became full resulting by these typhoons. This shows the positive impacts of typhoon but, in some year, it also causes the severe damages from flash flood.

Water demand in this basin can be classified by socio-economic purposes and non-socio-economic purposes.

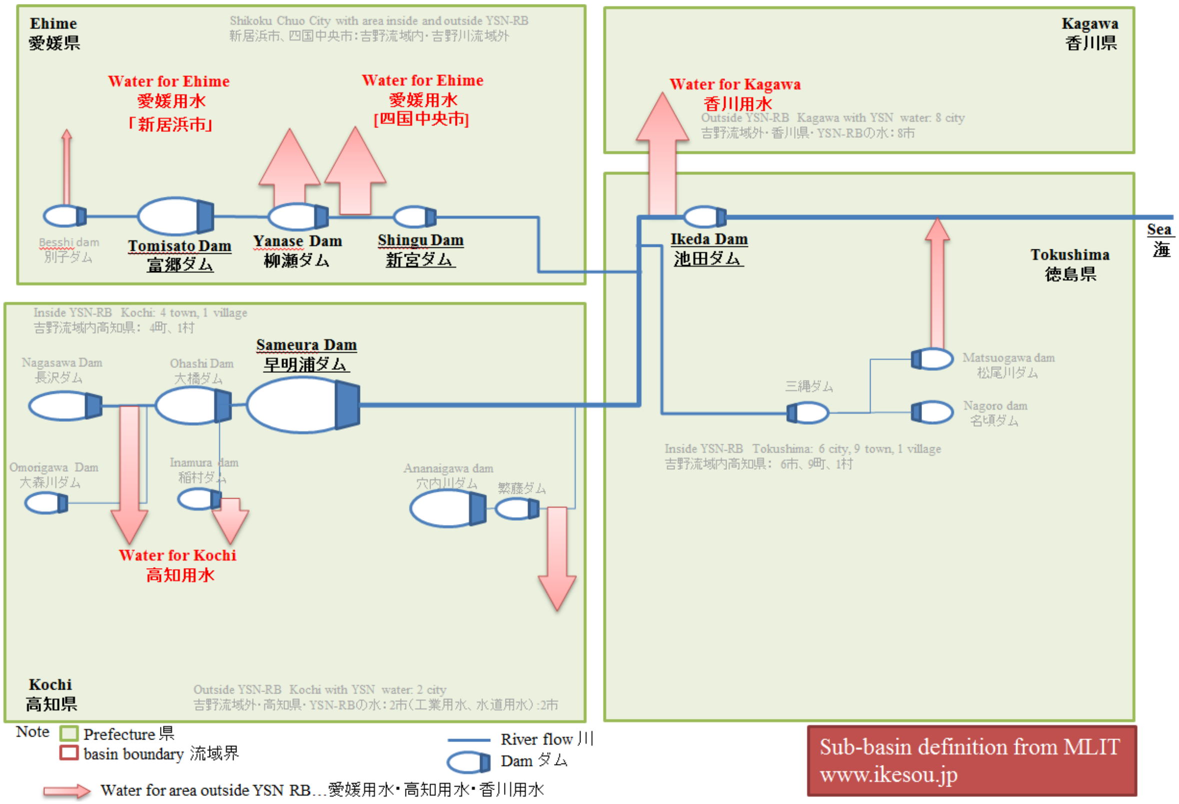


Fig. 5. Dam system in Yoshino river basin.

Socio-economic water demand is greatly related to water uses to meet demand not only in industrial sectors of agriculture, manufacturing, and for services resulting from economic development, but also for household purposes resulting from population growth. This competition has resulted in pressure on the water resources system.

As these issues, water is certainly essential for life and intimately linked with socio-economic development. This causes policy makers to integrate economic and environmental issues for making decisions in integrated water resources management to meet demands of socio-economic development. One of the interesting points which is always claimed among each prefecture is that, on the one hand, Kochi in which Sameura dam is located consumes less water than the other areas. On the other hand, Kagawa which is located outside this basin requires water approximately 20 % of total demand in this river basin and its demand is greater than water demand in Kochi. When drought occurs, the area located outside the basin including Kagawa prefecture will be the first stakeholder whose water is cut. For example, in 2005, there is no water storage in Sameura dam during the summer season. This causes the largest water cut resulting in economic damage on food industry of Kagawa which consumes a lot of water for its productions rather than the other prefectures.

To overcome the above shortcomings of demand and supply sides, the river committee is established to manage water demand-supply and to address the problem of flood and drought. The main objective is (1) to generate the database to make better understanding among each prefecture, (2) to analyze the problem in the past and the possible problems in the future, and (3) to prepare the adaptation policy for the future uncertainties.

2.5 Utilization of Hybrid water IOT in regional management

The above water problems and water resources management in Yoshino river basin can demonstrate the use of hybrid water IOT in regional water management. For simplicity in this paper, the traditional IOT of Yoshino river basin is collected from inter-regional IOT of Shikoku region generated by Suttinon at el (2013). However, this IOT is downscaled from regional level to Yoshino river basin and is verified by the additional socio-economic information of area which gains benefit from Yoshino river basin. Water account in this basin is also calculated by the same downscaling approach. For a reliability reason, this downscaled IOT and water account of Yoshino river basin are compared with the data of value added and real water use collected by governmental agencies.

3. RESULTS

The hybrid water input-output table of Yoshino river basin are generated and illustrated in table 1. As can be seen in this table, the row of water account in each industrial sector and each region is entered in the traditional IOT. There are two units in this hybrid water IOT: monetary unit showed by normal characters and physical unit illustrated in italic characters. It should be noted that the row sum is the summation of value in the same row; however, the column sum cannot be calculated by the summation of values in the same column. This is because the column consists of two types of unit.

To compare water use in each industrial sector, agricultural water demand is the main water consumer for both region located in- and outside Yoshino river basin. This is the general structure of water use for many countries. On the one hand, water quantity showed in the column illustrates the water demand to meet the economic goods and services. On the other hand, water used by citizen for household purpose is illustrated in the column of final demand. The row sum of water represents the water to support the socio-economic activities.

This developed hybrid water input-output table can be used not only for the descriptive device to understand the economic structure and water account as shown in table 1, but it can be also used as analytical tool to evaluate the policy declared by the government.

Table 1. Hybrid water input-output table for Yoshino river basin.

Unit: 10^11 JPN, * 10^6 cubic meter

Supply \ Demand			Intermediate transaction (IT)								Final demand	Total output
			Inside Yoshino basin: I				Outside Yoshino basin: O					
			A	M	W	S	A	M	W	S		
IT	I	A	0	1	0	0	0	1	0	0	0	2
		M	0	8	0	4	1	12	0	8	8	41
		*W**	*470*	*345*	*236*	*21*	*0*	*0*	*0*	*0*	*246*	*1318*
		S	0	4	0	11	0	3	0	5	52	75
	O	A	0	1	0	0	16	76	0	13	21	127
		M	0	9	0	5	26	1414	6	642	930	3032
		*W**	*0*	*0*	*0*	*0*	*54196*	*10557*	*13764*	*1756*	*11514*	*91787*
		S	0	5	0	8	18	598	21	1597	3876	6123
Value added			1	13	1	47	68	919	48	3818		
Total input			2	40	1	77	128	3032	81	6124		

Note: A, M, W, S = agricultural, manufacturing, water, and service sectors respectively.

For example, policy makers or water managers may want to know how much water they need to support the new policies of constructing new industrial estate, increasing number of tourists or expanding the area of paddy field. The following examples of new governmental policies to increase final demand of each industrial sector demonstrate the use of hybrid water input-output as an analytical tool.

Table 2 shows scenarios of additional final demand used for hybrid water IO model to evaluate the required water for each new final demand. There are 6 scenarios used in this paper, classified into 3 industrial sector (Agricultural, manufacturing, and service sectors) for 2 regions (in- and outside Yoshino river basin). Additional final demand in all cases is the same value as 10^{11} Japanese Yen. The approach is the same process as sensitivity analysis to value the impacts of additional final demand on water demand.

Table 2. Additional final demand in each scenario

Unit: 10^11 JPN

		Scenario					
		1	2	3	4	5	6
I	A	1	0	0	0	0	0
	M	0	1	0	0	0	0
	S	0	0	1	0	0	0
O	A	0	0	0	1	0	0
	M	0	0	0	0	1	0
	S	0	0	0	0	0	1
Sum		1	1	1	1	1	1

Table 3 demonstrates the calculation results of required water for all scenarios. By using hybrid water IO analysis with the above scenarios, it is almost certain that agricultural product requires a lot of water in production process in both in- and outside Yoshino river basin. The difference of water demands between both areas may cause by the type of agricultural product for example paddy field generally consume greater water than fruit farm. The service sector use water as the lowest ranking. This is because service sector generally use water in utility process, not in production process as same as agricultural and manufacturing sectors.

Table 3. Required water demand in each scenario

Unit: 10^6 cubic meter

	Scenario					
	1	2	3	4	5	6
I	286	22	2	0	0	0
O	0	30	6	587	38	8
Sum	286	52	8	588	39	8

4. CONCLUSION

Hybrid water input-output model can be used not only as a descriptive device to understand the relationship between economic structure and water account in certain year, but also as an analytical tool to quantify the water required to meet the new policy of economic development with inter-industry connections between each region. This model presented here is workable with the application in the river basin level.

Future research should be focused on water analysis based on a three-part structure: atmosphere, environment, and economy. By using this combination, we can include impacts of climate change into the water input-output analysis. Another interesting topic is how to invest under the conditions of changing supply and demand caused by uncertainties of climate change and economic development with the limited budget. To overcome this issue, real option should be considered as an analytical tool to address this difficulty (Suttinon et al. 2010, 2012). This is useful for the future planning.

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