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## Article

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## **An Important Perspective on Urban Management: The Application of Material Flow Balance Model to the Past Recycling Society in Japan<sup>1</sup>**

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**ABSTRACT.** Since the industrial revolution, growing and active economic activities in urban area have disrupted sustainable material flow balance in the environment, and the imbalance has induced some serious environmental problems. In order to realize proper urban management, taking measures to keep well-balanced material flow between urban and rural area is necessary. It is considered by historians that Edo, the old name for Tokyo, was environmentally friendly with its material recycling system developed. This paper develops a material flow balance model to quantitatively investigate the impacts of economic activities on the quality of the environment and the effects of the recycling system of Edo. A simulation result by the model shows that the water quality of Edo-bay (present day Tokyo-bay) was 0.095mg/L in the water quality index of total nitrogen (T-N). This value is within the optimal range for the cultivation of Nori, a kind of seaweed essential for Japanese traditional food Sushi. This result means that the recycling system contributed not only to the environment of the Edo urban area but also to seafood production in Edo-bay, and implies the importance of material flow balance for optimal and sustainable urban management.

**KEYWORDS.** *Evaluation model, economic activity, environmental problem, global eutrophication, material flow balance*

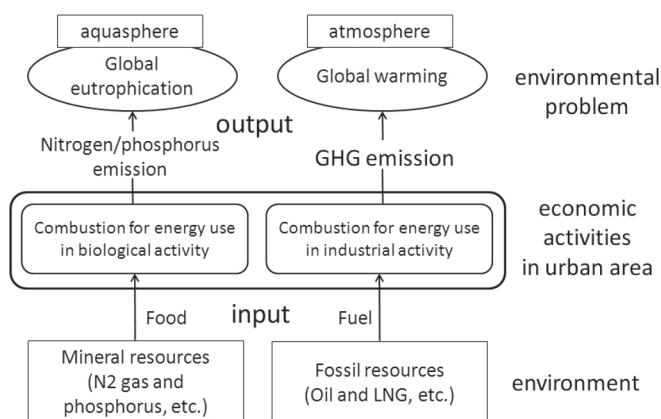
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## 1. INTRODUCTION

From a historical perspective of environmental problem, the consumption of fossil fuels since the Industrial Revolution continues to increase and cause many kinds of environmental problems. Our socio-economic system has been constructed under the influence of the Industrial Revolution for a few centuries. Previously, our society has experienced some kinds of environmental problems, for example, local industrial pollution, cross-border air pollution, etc., which grow into a more serious problem. After all, these environmental problems have been generated by pollution emission from combustion of fossil fuels in our economic activities. In recent years, global environmental problems such as global warming and air pollution have become international issues. In particularly, we can recognize two types of global environmental problem in atmosphere and in aquasphere. Figure 1 modified from Takahashi (2007) shows the structure of two types of global environmental problem, and the relationship between economic activities in urban area and the global environmental problems. Global warming, which is the famous environmental problem in the world, is mainly caused by GHG emission into atmosphere from combustion of fossil fuels and resources for energy use of industrial activities in urban area. Also, in the aquasphere, the global eutrophication is caused by nutrient salts increasing in the rivers, lakes, and oceans, and occurs by the same mechanism as the global warming. It should be noted that the eutrophication problem is also the global and immediate environmental problem. Clarifying the impact of economic activity in urban area on the water environment is important, and it is useful for urban management system balanced environmental concerns with socio-economic activity.



**Figure 1.** Structure of global environmental problem in aquasphere and atmosphere

**NOTE.** Modified from Takahashi (2007)

The purpose of this study is the evaluation of the relation between the urban activity and the water environment, especially focusing eutrophication, by the case study using material flow balance model. It is commonly considered that the society of the Edo period had maintained well-balanced relations with the water environment in Japan. One reason might be so that the human waste was recycled in the farmland as the organic fertilizer. We focus the Edo society, which had the recycling system in the urban area, and estimate the water pollutant emission from the socio-economic activity. Such a quantitative analysis can clarify the good situation of the water environment and the system of the past society from the viewpoint of urban management. In this study, the socio-economic and environmental model of Tokyo-bay basin will be built for quantitative analysis of the environmental impact on the water environment by the socio-economic activities in urban area.

Kawashima (2006) analyzed the water pollutant from the point of view of the agriculture, which estimates total nitrogen (T-N) emission and its cycle in the Edo era. However it mainly makes an analysis of the water pollutant emission from the food production in the farmland, and the target areas are all areas of Japan. On the other hand, Sakurai (2008) and Sakurai et al. (2009) estimated the water pollutant emission by socio-economic activities that mean population, industry, and non-point sources, and compared the impact on the water environment between deferent periods, the Edo period and the present. This study use the same approach as these studies regarding the estimate of impact on water environment, however, we develop the model to evaluate the effects of the recycling system of Edo, and to simulate the water quality of Edo-bay from the viewpoint of urban management. Moreover our model also incorporates a mechanism of the resource recycling system that means utilizing human wastes as the organic fertilizer. Nowadays the recycling system does not exist in our society, however this is the key to achieve the well-balanced water environment in Edo period (Council for Science and Technology Policy, 2005). Analyzing the recycling system of the Edo period can clarify the state of water environment in the past.

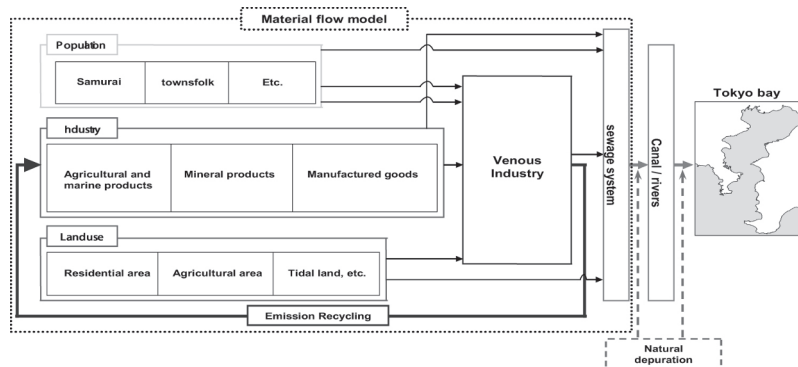
## **2. THE MODEL**

### ***2.1. Structure of the model***

In this study, the material flow model is built to make a quantitative analysis of environmental impact by human activity and the land use in the land area of Edo city. The framework of the model of Edo city is shown in Figure 2. In this model, it is assumed that the urban activity that means the population and the industry section, and land use make an impact on the water environment. The venous industry means that the farmers in or near the Edo city recycled the

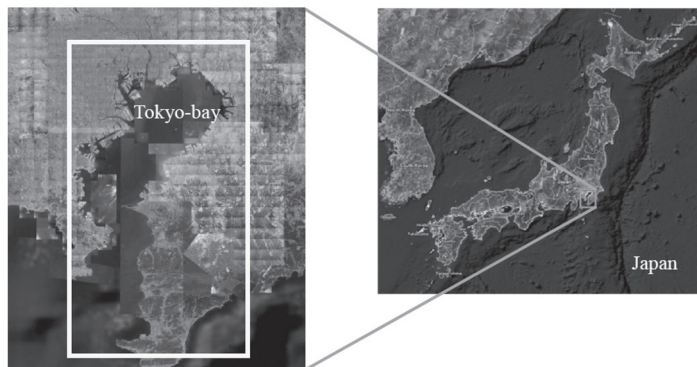
human wastes of the inhabitants as the organic fertilizer. The water environmental load will flow into the Tokyo-bay via sewage system in the city and canals/rivers taking account of natural depuration.

The target urban area is the Edo city and Tokyo-bay area shown in **Figure 3**, which is the largest urban area in Japan, and it is assumed as the stage of socio-economic activity. The target periods of this study is 1800s, which is the proto-industrialized age in Japan. The socio-economic situation and the land use pattern in the period will be analyzed by quantitative approach. The socio-economic situation is described by population, economic and infrastructure data, and the land use pattern is represented by GIS data. We will try to build the model related with socio-economic situations, the land use pattern and the water environment of Tokyo-bay. The model can estimate the impacts on the sea water environment by socio-economic and environmental factors of land-area.



**Figure 2.** Framework of material flow model of Edo system

**NOTE.** Reprinted from Sakurai (2008)



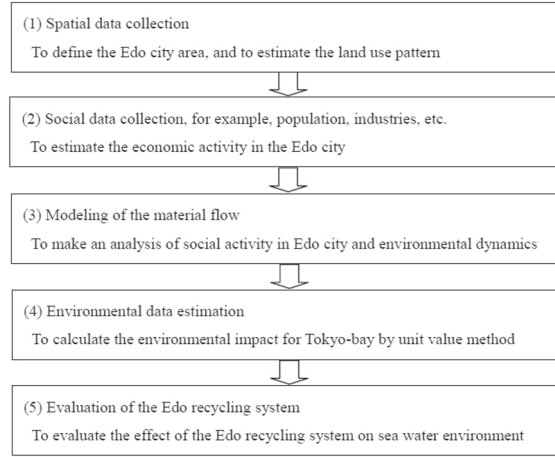
**Figure 3.** Tokyo-bay area

**NOTE.** Reprinted from Sakurai (2008)

Next, the estimation procedure of the environmental impact into the Tokyo-bay from the land area of the Tokyo-bay basin is shown in **Figure 3**. In this study, the environmental impact means the quantity of the water pollutant inflow, which is emitted by socio-economic activities from the land area of the Tokyo-bay basin. We try to estimate the water pollutant inflow into the Tokyo-bay in the Edo period.

The Edo city area will be spatially defined by the digital map from old data and materials such as the old picture map (Tokyo Metropolitan Archives HP) to estimate the socio-economic activities of Edo city in the Edo period. The model of the social system of Edo city will be constructed to analyze the material flow balance of the Edo city area, and the collected social quantitative data of Edo, which consists of the habitancy, the socio-economic activities, and the land use will be applied. And the environmental impacts from social activities in the land area of Edo city into Tokyo-bay will be estimated by unit value method. The model will estimate the total amount of environmental index such as T-N (Total Nitrogen). In this model, the water pollutant source from the land area of the Edo city is classified into three kinds of categories, which are the household sector, the non-point source, and the industrial sector. The water pollutant emission of household is estimated by population of Edo city, and the water pollutant emission of industrial sector is estimated by livestock industry and other industries. The water pollutant emission of non-point source means that of the land use area of Edo city.

The procedure of analysis in this study is shown by **Figure 4**. The procedure (1) and (2) in **Figure 4** means the estimation of the land use area and socio-economic activities of Edo city. We build a model of material flow including the recycling system of Edo society in procedure (3). The water pollutant from each emission source is estimated by unit value method (Kunimatsu and Muraoka, 1989) in procedure (4). The unit value method is the methodology for calculating the amount of emissions by the various sources. Each source of emission has the specified coefficient of each pollutant. We can calculate the total amount of emission using the methodology. And procedure (5) is the evaluation of the effect on sea water of Tokyo-bay by the recycling system of Edo society.



**Figure 4.** Flow of analysis

## 2.2. Household sector

The household waste water is generated from human activity in the land area of the Edo city, and the amount of the water pollutant emission is estimated by the population of the Edo city.

The coefficient of pollutant emission by population and the natural depuration ratio are quoted from the report of Council for Science and Technology Policy (2005). The estimated population, its water pollutant emission coefficient, and the recycling rate of human waste are shown in Table 3.

The amount of the water pollutant emission from population of Edo city is calculated as follows:

$$WP_H^j = E_H^j \cdot Pop \cdot (1 - R_H) \cdot (1 - Nd) \cdot 10^{-3} \cdot 365 \quad (1)$$

in which,

$WP_H^j$ : Amount of water pollutant emission  $j$  by household sector (kg/year)

$E_H^j$ : Coefficient of water pollutant emission  $j$  by population (g/person/day)

$Pop$ : Population of Edo city (person)

$R_H$ : Recycling rate of human waste

$Nd$ : Natural depuration ratio of water pollutant

$j=1$  (=T-N)

### 2.3. Industrial sector

Total amount of the water pollutant emission from industrial sector is summation of 5 industries, which are livestock industry, wood products, feeding stuff, food, and paper & products, shown in Table 4 and Table 5.

Total amount of water pollutant emission by industrial sector is calculated as follows:

$$WP^j = WP_{LI}^j + \sum_{i=1}^4 WP_i^j \quad (2)$$

in which,

$WP^j$ : Total amount of water pollutant emission  $j$  by industrial sector (kg/year)

$WP_{LI}^j$ : Amount of water pollutant emission  $j$  by livestock industry (kg/year)

$WP_i^j$ : Amount of water pollutant emission  $j$  by industry  $i$  (kg/year)

$i=1...4$  (See Table 6)

The activity of the livestock industry and the livestock waste causes influencing water pollution in the basin. Table 4 shows that 1,002 cows were bred in Edo city area in 1874. It is assumed that the recycling rate of water pollutant emission by the livestock industry and the natural depuration ratio are as same as the case of human waste.

Total amount of water pollutant emission by the livestock industry is calculated as follows:

$$WP_{LI}^j = E_{LI}^j \cdot Cow \cdot (1-R_{LI}) \cdot (1-Nd) \cdot 10^{-3} \cdot 365 \quad (3)$$

in which,

$WP_{LI}^j$ : Coefficient of water pollutant emission  $j$  by livestock industry (g/cow/day)

$Cow$ : Number of cows (cow)

$R_{LI}$ : Recycling rate of livestock waste

$Nd$ : Natural depuration ratio

Other industries mean 4 industries, which are wood products, feeding stuff, food, and paper & products shown in Table 5.

The water pollutant emission by the activities of these industries is calculated as follows:

$$WP_i^j = V_i \cdot PI_i \cdot E_i^j \cdot (1-Nd) \cdot 365 \quad (4)$$

in which,

$V_i$ : Value of production of industry  $i$  (100 million yen)

$PI_i$ : Price index of industry  $i$

$E_i^j$ : Coefficient of water pollutant emission  $j$  by industry  $j$  (kg/day/100 million yen)

$i=1...4$  (See Table 5)



#### 2.4. Non-point source

The water pollutant emission from the non-point source is estimated by the land use area of the Edo city. The land use pattern and its each emission coefficient are shown in Table 6. The land area of each land use is measured by digital map of Edo city shown in Figure 6.

The coefficient of pollutant emission by land use is quoted from the Japan Sewage Works Association (2001), and the natural depuration ratio is quoted from the report of Council for Science and Technology Policy (2005).

The amount of the water pollutant emission from the non-point source is calculated as follows:

$$WP_N^j = E_N^j \cdot L_k \cdot (1 - R_H) \cdot (1 - Nd) \quad (5)$$

in which,

$WP_N^j$ : Amount of water pollutant emission  $j$  by non-point generation source (kg/year)

$E_N^j$ : Emission coefficient of water pollutant  $j$  by non-point generation source (kg/ha/year)

$L_k$ : Area of land use  $k$  (ha)

$k=1 \dots 1$  (See Table 4)

#### 2.5. Total water pollutant from urban area

The total amount of water pollutant inflow from Edo city area into Tokyo-bay is derived by summation of water pollutant from household sector, industrial sector, and non-point source as follows:

$$TWP^j = WP_H^j + WP_I^j + WP_N^j \quad (6)$$

in which,

$TWP^j$ : Total amount of inflow of water pollutant  $j$  from Edo city into Tokyo-bay (kg/year)

#### 2.6. Water quality of Tokyo-bay

The water quality at the mouth of Tokyo-bay is calculated as follows:

$$WQ^j = \frac{TWP^j \times 10^6}{TI} \quad (7)$$

in which,

$WQ^j$ : Water quality at the mouth of Tokyo-bay (mg/L)

$TI$ : Total inflow of water from Edo city into of Tokyo-bay (L/year)

The total inflow of water from Edo city into the Tokyo-bay is derived from equation (7).

$$TI = \sum_r RI^r \quad (8)$$

in which,

$RI^r$ : Streamflow of the river  $j$  flowing into the Tokyo-bay (L/year)

$k=1...4$  (See Table 8)

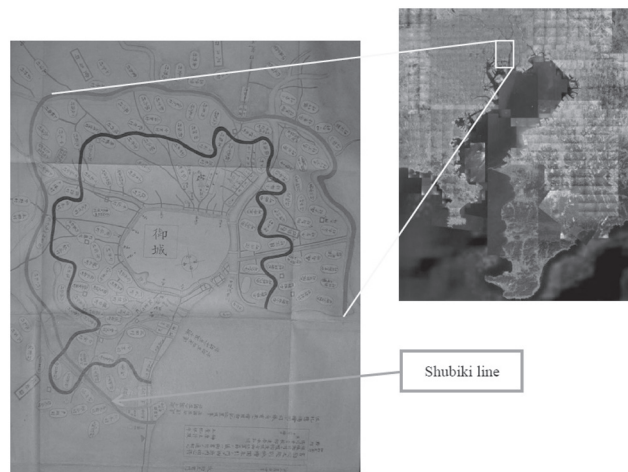
### 3. CASE STUDY

#### 3.1. Target area

In this study, the target urban area is the Edo city in the 19<sup>th</sup> century as the catchment area of a part of Tokyo-bay. The target period is the end of Edo era, because the Edo city seemed to have the most unpolluted water environment in the world at that time, and the data availability. Edo is an old name of Tokyo, and the Edo period was from 1603 to 1868. In 1603, the Shogunate Government of Edo was opened, and this era was ruled by the feudality during 265 years. At the time, Edo was one of the largest cities in the world, the population of Edo city was about one million people (Kito, 1989). And Edo had a character of consumption city, because it was a heartland of politics and there were a lot of samurais which were non-laboring class. It is called that the water environment in European cities had become aggravated by water pollutant emission from human activities at the same period of Edo era, for example, the Seine River was polluted by socio-economic activities in the land area. On the other hand, Tokyo-bay of Edo period was in an ideal situation though Edo city had a lot of population than London and Paris. And it is said that the Tokyo-bay was an ideal marine environment under the ecosystem that there were various fish species and a lot of fishing, and an excellent water quality maintained in Edo period through the 17-19<sup>th</sup> century. However, actual condition of water environment of Tokyo-bay and its basin were not clarified in Edo era, and the social system and marine environment in that period had not been quantitatively researched. In this study, it is tried to analyze the social system of Edo city, which had waste and sanitation recycling system, and to build the material flow model of Tokyo-bay basin in Edo period.

It is focused on delimitation of the Edo city area on the basis of the official announcement by government of Edo in 1818, and estimating social and economic activities in the Edo city area. The city area of Edo is a part of present Tokyo metropolitan area. The city area of Edo has developed as a political city of Japan through the Edo era. The Edo city area called “Shubiki” was spatially defined by the conference chamber of Edo government in 1818. The left drawing in Figure 5 is the published picture map by the conference chamber of Edo government in 1818.

The area of the Edo city is unclear from this map, because the Edo government had no scientific survey at the time. Figure 5 shows the location and the area of Tokyo-bay of our own time. Tokyo-bay is situated in Kanto region of Japan in present day. Tokyo-bay is one of the largest enclosed coastal sea areas in Japan.



**Figure 5.** Edo city area (Shubiki) published by the Edo government in 1818

### ***3.2. Edo city area and land use***

One of the important subjects of this study is to build a refined electronic map of the Edo city. In this section, the spatial area of the Edo city will be delimited by digital mapping using GIS.

Formerly, we have some maps built by the Meiji government using the Tokyo Datum in Meiji period (1868-1912, after Edo period). The Meiji map is the first cartograph on a scientific system in Japan, now we have no digital map of the Edo city area. In Japan, the geographic coordinate system has been used by the Tokyo Datum from 1918 (Taisho period; 1912-1926, after Meiji period) to 2002, which is based on Bessel ellipsoid to make a measurement of the datum point. However, the WGS84 (World Geodetic System 1984) is now used as a world standard system after April 1st, 2002. The Tokyo Datum caused about 450 meters of distance error as compared the WGS84, because the datum point is both deferent.

Figure 6 shows the digital map that defines a boundary of the Edo city using GIS. This digital map is based on the new geographic coordinate system called WGS84.



**Figure 6.** Digital map of Edo city area (Shubiki)

Next, the land use pattern of the Edo city area (Shubiki) is classified into 11 categories shown in Table 1. The data of land use is obtained from some materials such as the Edo cartograph by Masai (2000), Department of the Army General Staff (1880-1886), etc. Figure 7 is the newly-electronic map digitized geographic information of land use in the Edo city area on GIS, which can be estimated the area of each land use that classified into 11 categories shown in Table 1 and Figure 7. The each emission coefficient of the water pollutant T-N is estimated by reference to Ogura (1993) and Japan Sewage Works Association (2001).

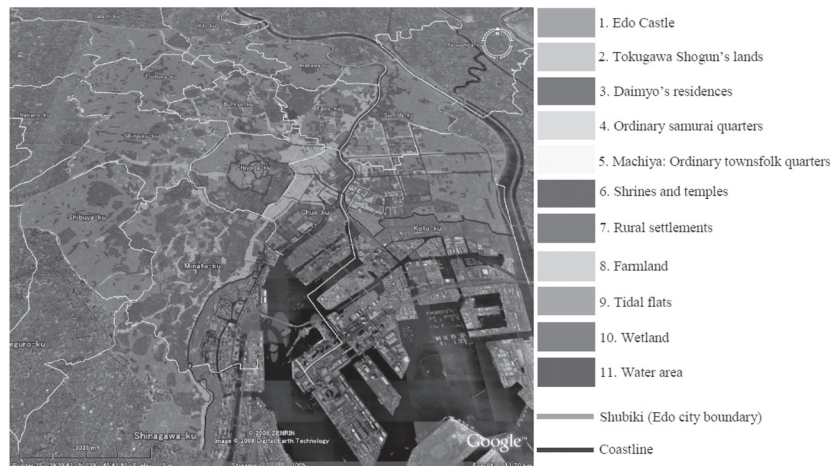
**Table 1.** The area and emission coefficient of each land use

Index <i>k</i>	Land use	Area (ha)	Coefficient of water pollutant emission <i>j</i> (T-N) (kg/ha/year) T-N
1	Edo Castle		16.5
2	Tokugawa Shogun's lands		16.5
3	Daimyo <sup>2</sup> 's residences		16.5
4	Ordinary samurai <sup>3</sup> quarters	8,468	16.5
5	Machiya: Ordinary townsfolk quarters		16.5
6	Shrines and temples		16.5
7	Rural settlements		16.5

2. feudal lord

3. bladesman

8	Farmland	7,071	29.3
9	Tidal land	676	0
10	Wetland	37	0
11	Water area	671	0
Total		16,924	



**Figure 7.** Land use pattern of Edo city on present map of Tokyo by GIS

### **3.3. Population of Edo city**

In Japan, population data of 1721 is the oldest, which was summarized respectively in each region of the country. In Table 2 the population of the metropolitan area of Edo is estimated based on population census (Edo Shogunate, 1843), in this study, the population of the Edo metropolitan area is approximately 1.1 million (the population of Townsfolk (Cho-nin) is 587,458, the population of Samurai (Buke), Court noble (Kuge) and Others is 512,542) by reference to Naito (1966) and Kito (2002). And Table 2 also shows the coefficient of water pollutant emission, which is T-N (Total Nitrogen) in this case, the coefficient is determined reference to Japan Sewage Works Association (2001).

**Table 2.** Estimated population of Edo city and emission coefficient in 1843

Index	Status	Population	Coefficient of T-N emission (g/capita/day)
1	Townsfolk (Cho-nin)	587,458	11.2
2	Samurai (Buke)		
3	Court noble (Kuge)	512,542	11.2
4	Others		
	Total	1,100,000	

### 3.4. Economic activity of Edo city

Table 3 and Table 4 show the production and economic data in 1874. This data is the oldest one using a statistical method in Japan, and is adapted from Ministry of the People's Affairs (1875). The data of the industrial production value at that time is converted to the present value by reference to Research Department, Bank of Japan (1975) and Bank of Japan (1986). And the coefficients of water pollutant emission are determined reference to Japan Sewage Works Association (2001).

**Table 3.** Pollutant emission by livestock industry

Cow (1874)	Coefficient of T-N emission (g/cow/day)
1,002	290

**Table 4.** Product and pollutant emission by industrial sector (except livestock)

Index <i>i</i>	Industry (1874)	Product (Yen, in 1874)	Present value (Yen, in 2000)	Coefficient of T-N emission (kg/day/100million yen)
1	Wood Products	3,018	23,320,780	0.01
2	Feeding stuff	108	837,618	0.52
3	Food	9,098	70,301,638	0.74
4	Paper & Products	78,753	608,532,104	10.23

## 4. RESULTS AND DISCUSSION

### 4.1. Estimate of T-N emission by urban activity of the Edo city

Table 5 shows the calculation result derived from the material flow model, which is estimated the total amount of T-N inflow into the Tokyo-bay from the Edo city area that means the household sector, the industrial sector, and the non-point source of land area of the Tokyo-bay basin. In Table 5, the household sector and industrial sector has each 540 tons and 26 tons of T-N emission with recycling the human and the livestock waste for farming. It is estimated 208 tons of T-N emission from non-point source. This model incorporates the recycling system of the Edo city and utilizing the human and the livestock waste for farming as the fertilizer. In case of Table 5 the recycling rate is 80%, because the Council for Science and Technology Policy (2005) estimate that the recycling rate of human waste in the Edo city was about 80%.

**Table 5.** Estimated total amount of water pollutant inflow into the Tokyo-bay (tons/year)

Year	Land area	Water pollutant	Source			Total inflow
			Household	Industry	Non-point	
1843	Edo city boundary (162km <sup>2</sup> )	T-N	540	26	208	774

### 4.2. Effect of the Edo recycling system on the water environment

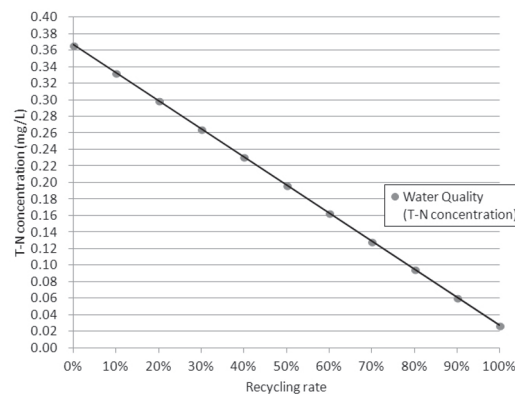
Next, we estimate the effect of the Edo recycling system on the water environment of the Tokyo-bay by the simple model simulation. That means that the model clarifies the impact of recycling and utilizing of the human and livestock waste for farming with a quantitative index T-N. The water quality at the mouth of the Tokyo-bay is obtained to divide the amount of T-N by the volume of the river inflow into the Tokyo-bay. In this calculation, there are 4 inflowing rivers into the Tokyo-bay that are shown in Table 6, each river has a different flow condition (Nihei et al., 2007). The total volume of the river inflow into the Tokyo-bay is the summation of that of 4 rivers.

**Table 6.** Flow conditions of inflowing rivers into the Tokyo-bay from Edo

Index	River name	River Inflow	Unit
1	Tamagawa river	38	m <sup>3</sup> /s
2	Sumidagawa river	80	m <sup>3</sup> /s
3	Edogawa river	75	m <sup>3</sup> /s
4	Nakagawa river	65	m <sup>3</sup> /s

(Nihei et al., 2007)

Anyway, the model can calculate the T-N concentration as the sea water quality at the mouth of Tokyo-bay, when the recycling rate is changed from 0% to 100%. According to the Council for Science and Technology Policy (2005), the recycling rate of human and livestock wastes in the Edo city is regarded as 80%. If it can be taken, the T-N concentration of the Tokyo-bay is derived 0.095 mg/L from our model simulation. Also the relation between the recycling rate and the T-N concentration is shown in Figure 8.

**Figure 8.** Relation between recycling rate and the water quality

#### 4.3. Discussion

According to the Ministry of the People's Affairs (Minbu-sho) (1875) and the Publishing Association of the Rise and Fall History of Fishery in the Inner Bay of Tokyo (1971), the fishery in the Edo period was very active in the Tokyo-bay, and the catch of fish and shellfish were too much larger than the present. Especially it is confirmed that the Nori cultivation began during the



Edo period. In fact the water environment at the mouth of the Tokyo-bay was suitable for the Nori cultivation (The Publishing Association of the Rise and Fall History of Fishery in the Inner Bay of Tokyo, 1971). On the other hand, Ueda (1973) suggested that the optimal water quality for the Nori cultivation is from 0.078 to 0.098 mg/L of T-N concentration. Referring to our simulation result in Figure 8, you will find that the recycling rate of the human and livestock wastes of the Edo system is between 85.1 % and 79.2% to maintain the water quality for the Nori cultivation near the Tokyo-bay area. Therefore, it is reasonable to support that the initial assumption of the recycling rate is 80% in this study, and the urban activities have close interaction with the water environment.

## 5. CONCLUSIONS

This study clarified the following three points.

First, the urban system that consists of population, industry, and land use was quantitatively defined in the Edo period to present the basic concepts of urban management from the environmental viewpoint. And we defined the boundary of Edo city, and convert the map data into digital data, and structured other related data.

Second, the material flow balance model was built to incorporate the recycling system of Edo city, and estimated the impact on the water environment of Tokyo-bay. We focused on the unique recycling and utilizing system of the human and livestock wastes as the fertilizer, and estimated the T-N inflow into the Tokyo-bay from the Edo city. The estimate of total amount of T-N inflow was 774 tons/year, if the recycling rate is 80%.

Finally, we discuss the effect of the Edo recycling system on the water environment of the Tokyo-bay. The fact that the Nori (seaweed) cultivation actually existed near the Tokyo-bay at that time indicates that the water quality of Tokyo-bay met the condition of the Nori growth. To become available for the Nori cultivation, it is necessary to be between 0.078 mg/L and 0.098 mg/L of the T-N concentration. Thus, the recycling rate of the Edo system, which could clear the condition for the Nori cultivation, is calculated by model simulation. In the result the recycling rate is between 85.1 % and 79.2%, and this calculation result proved that the initial assumption of the recycling rate was appropriate.

In conclusion, the analysis in this study suggests that the urban activity of the Edo city including the recycling system maintained perfectly-balanced relations with the water environment. It may be said that the Edo recycling system affected an impact on the water quality of the Tokyo-bay, aquatic resources, and ecosystem in the basin. In the 21st century the eutrophication phenomena occur in many places of the world because of the socio-economic activity, the government regularly implements the total effluent and pollutant load control

system. However, according to the relation between the water quality and ecosystem in the water environment, a proper balance of nutrient salts is needed for the urban management.

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