PROBLEMS OF WATER IN TOKYO

Kunio ARAI*

I. INTRODUCTION

There is no general way to maintain the equilibrium between available and consumed water, except by making the former larger or the latter smaller. The quantitative relationship between available water and the water being consumed in Tokyo is critical now; however, this is not a matter that is widely recognized even in Tokyo. The present momentary equilibrium situation is supported by the deft tecnique of water control which is based on the facts that there are several sources of water and that there is a little difference of temporal variation regime between the available and being consumed water.

The present paper discusses two existing policies to solve the water famine in Tokyo; the year-to-year reservoir and water conservation. Both of these are the most immediately deficient projects among the many plans now in effect, which also include desalination of sea water, the recycling of sewage water, and leakage prevention.

II. OUTLINE OF TOKYO'S WATERWORKS

There have chronically been excessive demands for water in Tokyo since the initiation of the modern water supply system in 1891. Fig. 1 shows the recent yearly change of the maximum daily supply of drinking water and the maximum available volume of water. Both of these have increased by more than a factor of two over a period of only 15 years since 1960. The main causes for the sudden increase of water consumption are thought to be the population increase plus the spread of urbanization and changes in living standards reflected in the employment of washing machines and flush toilets.

Although the quantity of available water has been increased from year to meet the growing demands, the relationship is still critical.

Fig. 2 shows the water conduction system for Tokyo. Fig. 2(a) shows the rivers whose water is fed to Tokyo. Tokyo has three sources. Water from the Tama River has been used for drinking in central Tokyo since 17th century. The capacity of the Ogochi Reservoir, which was completed in 1957 to develop new water resources for Tokyo, is 186 million cubic meters. The river would provide only about 35 percent of the water presently being consumed in Tokyo even if its entire runoff could be used, since the drainage area is only about 1,300 square kilometers. However, it is the only large river in the municipal territory

---

* **Department of Civil Engineering, Tokyo Metropolitan University.**

of Tokyo.

Nowadays, Tokyo depends on the Tone River for about 75 percent of its water. The flow control of this river is entrusted to the central government, since the drainage area of about 16,000 square kilometers is the largest in Japan and includes part of six prefectures. Since 1964, three dams, two weirs and two canals have been built to conduct the water to the metropolitan area. And still there are more plans under way for new water resource development, such as the Yatsuba Dam and Kasumigaura Lake Development.

The third source is the Sagami River. Tokyo is buying the water from Kanagawa Prefecture, by which all the rights as to this river are owned.

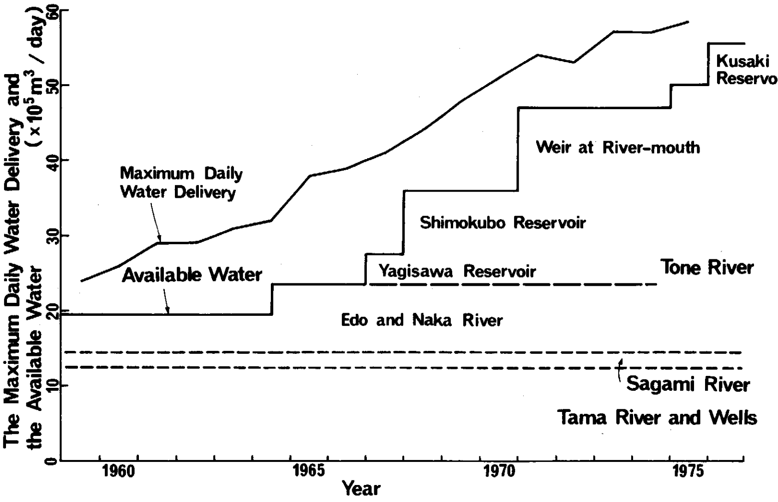
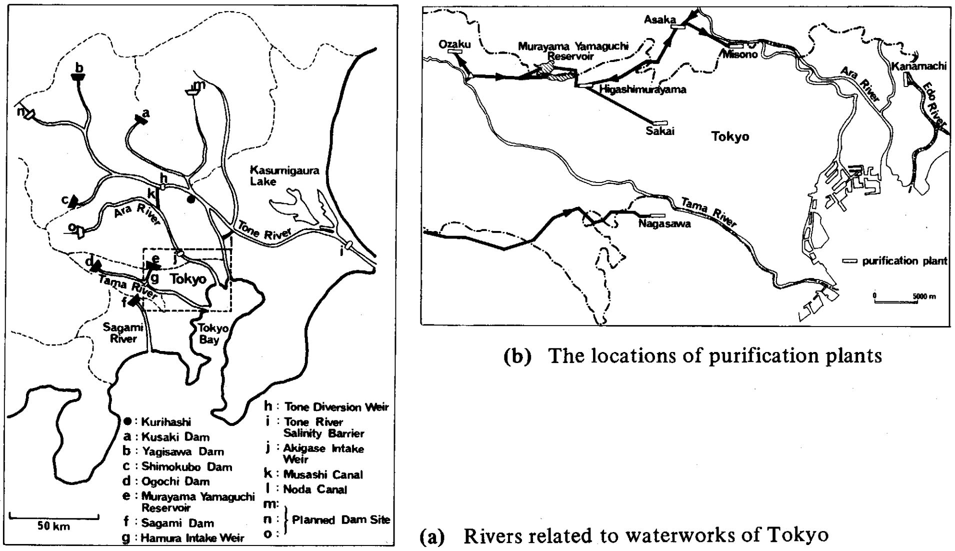


Fig. 1 The yearly changes of the maximum water delivery and available water.



(b) The locations of purification plants

(a) Rivers related to waterworks of Tokyo

Fig. 2 The system of water conduction of Tokyo.

Fig. 2(b) shows the locations of the seven main purification plants. Their total possible processing capacity is 5.76 million cubic meters per day. The water conveyance pipe between Higashimurayama and Asaka completed in 1964, should be noted. Although its initial purpose was to conduct water from the Tone to the Higashimurayama and Sakai plants, at the present time this pipe plays an extremely important role with respect to the conveyance in the opposite direction. The reason is exsited in urgent actions since 1973 that water stored in the Ogochi Reservoir has been sent to Asaka through this pipe each time water supplied from the Tone has been restricted. In August, 1973, for example, when the available water from the Tone River was reduced to 30 percent of normal, or 10 m^3/sec, water stored at Ogochi was supplied at the rate of 18 m^3/sec and water was sent at about 9 m^3/sec to Asaka using this pipe. As a result there were few problems, and there was no suspension of water supply in Tokyo.

III. INSTABILITY OF AVAILABLE WATER

The primary solution to the water crisis in Tokyo is to find additional sources so as to increase the available water. Almost all of the low flow volume of the Tone River had already been secured for irrigation by farmers until around 1900. Accordingly, the water of high flow produced by rainfall had to be stored by means of dams and weirs to obtain the water required in urban areas from the Tone. According to a plan by the Ministry of Construction (1973), at least 165 m^3/sec of Tone's water is to be used for a variety of purposes in the near future.

Fig. 3 shows the probabilistic flow duration curves from the data obtained over 25 years since 1948 at Kurihashi, shown in Fig. 2(a). From a rough examination of the line of the two years recurrence curve, and the 125 m^3/sec line which is equal to the present demands, the followings may be concluded.

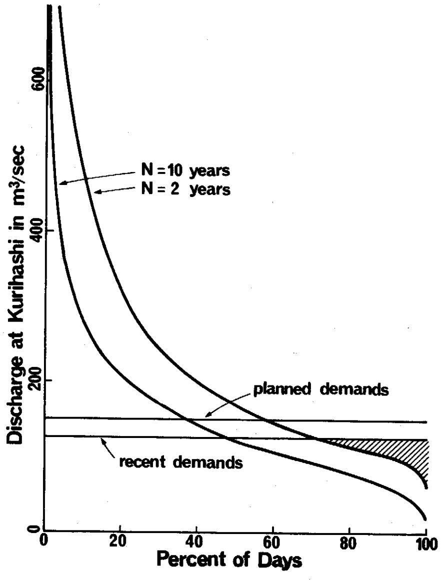
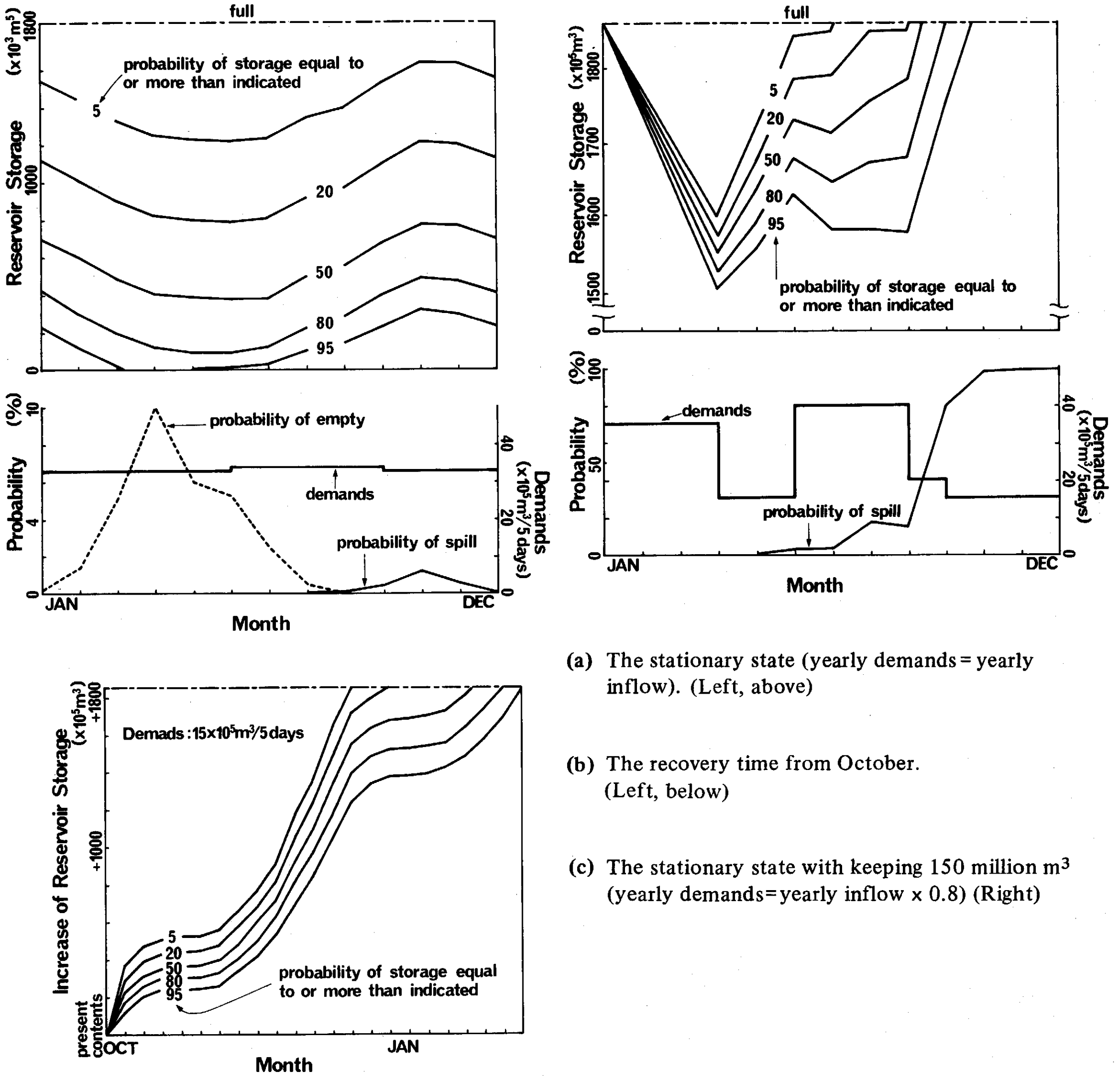


Fig. 3 The probabilistic flow duration curves and recent and planned demands.

1) The number of days which the daily average runoff is less than 125 m^3/sec may exceed 110 during a single year, and may occur bi-yearly.
2) Therefore, water of about 200 million cubic meters, equal to the shaded area, must be stored to ensure steady water usage at a rate of 125 m^3/sec regularly throughout a year such as above.

There is sufficient capacity in the Tone drainage to store the water since the total capacity of existing reservoirs is about 420 million cubic meters. However if we consider the ten years curve, about 800 million cubic meters of water must be stored for the present demands and 1,200 million for the planned demands at Kurihashi. It is a desperate measure to install dams with total capacitied of 400 to 800 million cubic meters since tremendous compensations would be needed for removal of homes. In short, the Tone might already have become insufficient to fill the future demands of the metropolitan area.



(a) The stationary state (yearly demands = yearly inflow). (Left, above)

(b) The recovery time from October. (Left, below)

(c) The stationary state with keeping 150 million m^3 (yearly demands=yearly inflow x 0.8) (Right)

Fig. 4 The probabilities of various storage stages of the Ogochi Reservoir

Water conduction to the Tone from neighboring drainages is to be planned formally in the near future. But all the users of the Tone's water will have to make do with the water presently available for a fairly long time from now because the plan may be attended with the delicate political negotiations between users and suppliers and therefore it will be needed for long time until the realization of it.

The Bureau of Waterworks in Tokyo is executing a temporary plan on the basis of the flow and demand conditions of the Tone as follows.

> In ordinary times, the water of the Tama River is stored in the Ogochi Reservoir as much as possible. And the remaining water of the Tone River is used instead of the water which should be supplied from the Tama. If the flow from the Tone become limited, the stored water will be discharged. This is the idea of year-to-year reservoir.

The Ogochi Reservoir, therefore, has to bear the great responsibility of being the last fuse in the water delivery system in Tokyo. The writer (Arai and Marui, 1979) has discussed the state of storage in the Ogochi using queing theory. Fig. 4 shows the results of this. Fig. 4(a) shows the stationary probabilities of the storage state. The capacity seems to be too large to handle the annual average inflow over the course of a year, because at least 60 percent of the capacity is idle on the average, and it is very rare that it is full. Fig. 4(b) shows the expected recovery time of storage when the discharges are limited as little as possible. Water of 140 million cubic meters may be stored over one year from October. Fig. 4(c) shows an example of the yearly discharge plan under the condition that the stored quantities must usually be more than 150 million cubic meters. The storage will not be guaranteed if the total discharge exceeds 190 million cubic meters, being about 80 percent of the average yearly inflow.

It might be relatively easy to find the dam sites among the upper Tone if the period more than a year could be adopted as the control cycle of stored water in reservoir like the Ogochi, because the areal size of reservoir's catchment may not be related to the main object to seek dam site. It was, in fact, started to plan the built of this type of reservoir in the Tone by the Ministry of Construction. And the same examinations as the one mentioned above, will be applied at each planned site.

IV. WATER CONSERVATION

Another important plan to solve the water crisis may be to restrain demand. The most effective method for this is to raise the charge.

Table 1 shows three year earnings and the gross and net expenditures per flow quantity for the yearly water consumption in Tokyo for 1974 through 1976. The earnings are less than not only the gross expenditures, but also the net expenditures consisting of only the running costs, such as the manufacturing, personnel and so on. The main reason for this is that the price of water is kept low regardless of the legal obligations to keep a self-suporting accounting system, because of the idea that the water is one of the most important materials for human life. Therefore all the water management bodies in Japan are usually operated at a deficit.

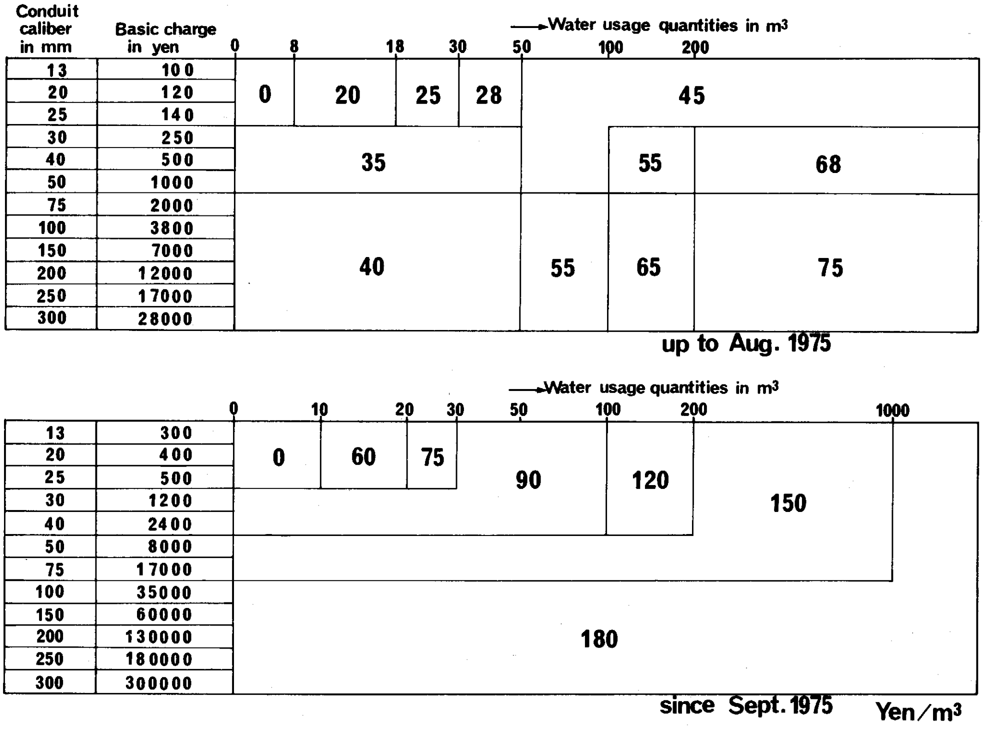
The gross expenditures of 1974 were about twice the earnings. This was the result of not

Table 1 The recent incomings and outgoings of the waterworks of Tokyo.

year		1974	1975	1976
Earnings	(Yen/m^3)	25	47	63
Net expenditures	(Yen/m^3)	37	38	43
Gross expenditures	(Yen/m^3)	49	54	67
Conducted water	(x 10^6 m^3)	1773	1896	1895

raising the rates for 8 years from 1968. During the same period the price index had doubled. To improve this inequality the charge rate was raised in September 1975. Fig. 5 shows the old and the new rates. Although the rate increases differ for each caliber of consumer pipe and for each usage quantity, the new charges are from twice to three times the old, on the average. There has been, but probable there will not be, such a raise as that again, since raises must be excecuted fractionally in connection with the price index.

Table 2 shows the earnings, the service numbers and the total quantities of water for each service pipe caliber during the same period as the above. The increased rates for small caliber earnings were greater than those for the larger. And the numbers and quantities for 30 to 150 mm caliber class became smaller from year to year. It is easy to imagine from these facts that the increase at that time gave a serious shock to the consumers of large calibers or to the users of large quantities. In fact, the average monthly required water for a gas works, which is the user of the largest volume of water in Tokyo for example, had



→Water usage quantities in m³

Conduit caliber in mm	Basic charge in yen	0	8	18	30	50	100	200
13	100	0	20	25	28	45		
20	120							
25	140							
30	250	35					55	68
40	500							
50	1000							
75	2000	40				55	65	75
100	3800							
150	7000							
200	12000							
250	17000							
300	28000							

up to Aug. 1975

→Water usage quantities in m³

		0	10	20	30	50	100	200	1000
13	300	0	60	75	90		120	150	180
20	400								
25	500								
30	1200								
40	2400								
50	8000								
75	17000								
100	35000								
150	60000								
200	130000								
250	180000								
300	300000								

since Sept. 1975 Yen/m³

Fig. 5 The charge tables up to Aug. 1975 and since Sept. 1975.

Table 2 The recent earning, service numbers and accounted water for each caliber conduit in Tokyo.

	Earnings (x 10^8 Yen)			Service numbers			Accounted volume (x $10^6 m^3$)		
year / Conduit Caliber in mm	1974	1975	1976	1974	1975	1976	1974	1975	1976
13	180	193	265	138 x10^4	136 x10^4	137 x10^4	766	476	479
20		111	158	57.6x10^4	61 x10^4	66.4x10^4		234	244
25		86.2	119	31.3x10^4	32.8x10^4	34 x10^4		147	148
		390.2	542	226.9x10^4	229.8x10^4	237.4x10^4		857	871
30	105	31.6	42.2	188 x10^2	191 x10^2	201 x10^2	175	33.6	33.4
40		97.3	126	283 x10^2	266 x10^2	264 x10^2		95.1	90.8
50		64.9	87.4	57.5x10^2	53.7x10^2	55 x10^2		53.1	51.4
		193.8	255.6	528.5x10^2	510.7x10^2	520 x10^2		181.2	175.6
75	160	106	133	41.2x10^2	36.7x10^2	36.7x10^2	214	81.7	75.1
100		64.1	78.2	12.3x10^2	10.4x10^2	10.2x10^2		46.9	40.5
150		67.1	88.7	420	410	409		47.6	47.8
200		28.3	36.3	86	84	93		20.7	19.4
250		24.4	34.8	34	52	49		16.6	19.1
300		16.8	20.7	13	17	17		11.2	11.2
		306.7	391.7	5903	5273	5258		224.7	213.1

decreased from 240,766 m^3 per month in 1974 to 171,257 m^3 in 1976.

On the other hand, the increase also influenced the small caliber consumers, since their value of the water volume per service number had decreased. But the influence here might have been less serious than that to the large users. If a family uses 25 m^3 of water per month, then the monthly charges increases from 430 yen on the old table to 1,275 yen on the new. The ratio of this new charge to the average income of a family in Japan is only about 0.5 percent.

Under the above circumstances, it may be very difficult to control the small caliber user's water by means of rate increases. But the savings of this domestic type use are the most important, since half of the total consumed water in Tokyo seems to be for domestic purpose. The minimum basic quantities of domestic use were estimated at 85 liters per capita per day by the Bureau of Waterworks (1973). According to research by the Ministry of Construction (1972), about 200 liters of water per capita is being consumed each day in the urban area, and this value may increase to 250 liters in the future. In Tokyo, if all the water in the 13 mm caliber class is used by only general families, and if the numbers of family members is four, then the yearly total quantities are calculated as follows.

Daily uses per capita (liters)	Yearly total use (x$10^6 m^3$)
85	169
200	397
250	496

In the author's family, with no special consideration for water saving in mind, the daily use per person varied from 136 to 168 liters during 1979. Accordingly it should not be so difficult to decrease the quantities of the small caliber users from 910 million m^3 in 1976 to 800 million or less.

Probably, based on those considerations the Bureau of Waterworks can call people's attention to water saving.

V. PROBLEMS IN THE FUTURE

This type of water famine has occurred not only in Tokyo, but in many big cities in Japan. The causes of such phenomenon, in spite of receiving rainfalls of about 1,500 mm during a year, may be that, naturally, the delay times of the surface runoff are short, due to the short and intensive rainfall conditions and the mountainous surface conditions, and that, socially, the population is unevenly distributed into large cities. Besides, it has recently been thought that the general attitude of the Japanese people is of importance. That is, almost all Japanese believe that there are infinite quantities of water freely available on the Japanese Islands, and that if water should become insufficient in a region, it can surely be conducted from other regions to meet demands.

The water famine problem in Japan will not be solved, but will become more serious over at least the coming several decades as long as the present attitudes towards water exist. The improvement of those attitudes may be possible only at the stage of primary education.

REFERENCES

Arai, K and Marui, N. (1979): Basic study for the operation of the Ogochi Rservoir in Tokyo – an approach from propabilistic hydrology – . *Comprehensive Urban Studies,* 7, 113–121 (in Japanese with English Abstract).

Bureau of Waterworks of Tokyo (1976, 1977, 1978): *Annual Reports of the Bureau of Waterworks* (in Japanese).

—— (1973): *Plan for Restraining Water Demands* (in Japanese).

Ministry of Construction of Japan (1972): *New Plan for Water Uses in the Kanto Region* (in Japanese).

Japan Waterworks Association (1977): *Annual Waterworks Statistics in Japan* (in Japanese).