DISSERTATION

WATER SUPPLY-DEMAND SYSTEMS IN THE ASHIDA RIVER BASIN
-WITH SPECIAL REFERENCE TO ANALYSIS OF WATER DEMANDS-

Submitted by

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ABSTRACT

In Japan, several regions are currently suffering from water shortage. However, there is little detailed information about actual conditions of water use. The objective of the study is to clarify the water demand structures in the Ashida river basin, one of the severe water-scarce areas, by using aggregated and individual data.

Rapidly growing industrial and municipal sectors have solved the water supply-demand problem by transferring water from agricultural sector. This water transfer was the pioneering work permitted on legal basis. Municipal sector was given a priority over other sectors under drought conditions.

From analysis of time series of water use, irrigation water use series show evident seasonal variations. Municipal and industrial water use series have increasing trends, weak seasonal variations, and striking depressions or negative jumps due to droughts. There is no reduction of water use due to change in price of water.

Municipal and industrial water demands are investigated in detail by using data of 1,135 establishments and 3,200 households obtained through the questionnaire survey.

There are significant differences in unit water use, which can not be fully explained by variables of type of establishment, industrial product, presence or absence of

ground water use and water-using appliances, for groups of industrial, commercial and public establishments.

Three types of residential water demand equations are tested by all-possible-regression analysis. A significant portion of the variation in water use can be explained by the number of persons in household, and the presence or absence of ground water use, of flush-toilet use, and of non-domestic water uses around the house. Income elasticity of 0.01 to 0.25 is consistent with that derived in the earlier study of Tachikawa city. Household-size elasticity of 0.10 to 0.75 is consistent with the previous cross-sectional studies based on individual data.

From cross-sectional and time series data on individuals, the price elasticities of demand for water are estimated around zero for most of sectors or groups.

There is a spatial difference in demand structure of residential water. Almost all of the variation in water use per capita can be explained by the uses of ground water and flush-toilet. With the increasing number of water-using appliances and the decreasing amount of self-supplied ground water, both residential water use in household and that per capita significantly increase. With increasing number of nuclear families, residential water use in household slightly decreases, and both that per capita and the number of supplied households increase. Total of residential water use in the municipality, therefore, steadily increases.

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I INTRODUCTION

1.1 Water Supply and Demand Problems in Japan

In most economically advanced countries, the water demands in urban areas have rapidly increased keeping pace with growth in urban population, expansion of industry and elevation in living standard. In Japan, agricultural sector has been utilized a major proportion of available stream water for a long time. The developments of urban areas and industrial production, therefore, have caused the conflicts in water allocation with agricultural sector.

The investigators have laid the main stress upon the political and administrative aspects of water allocation among different sectors, especially between the agricultural and the non-agricultural sectors (Shinzawa, K., 1962; Sato, T., 1965; Moritaki, K., 1966; Hanayama, Y. and Fuse, T., 1977; Shimura, H., 1977).

It has become difficult to develop additional supply source, because the cost of reservoir construction has drastically increased and the inhabitants in submerged villages have made the strenuous opposition toward dam construction. Several regions of Japan are currently suffering from water shortage. To solve the water supply and demand problems in the water-scarce areas, the need for rationalization of water use is emphasized, but the word "rationalization" is not clear in meaning.

To keep the balance of water supply and demand, the following measures were proposed (Shirai, Y., 1971; Kurosawa, S., 1972; Nakazawa, T., 1974; Hori, K., 1978; Yamamoto, I., 1978): (1) Construction of "estuary reservoir" at the mouth of the river, (2) Water transfer from agricultural sector within the basin, (3) "Interbasin water transfer", (4) Construction of the dual supply system by utilizing wastewater. The water allocation in the basin or among the basins was studied by using the system dynamic models (Takasao, T. and Ikebuchi, S., 1977; Miyoshi, I., et al., 1978; Yoshikawa, K., et al., 1978). In these models, the future water demands were estimated through the requirement approach. This approach uses figures for expected supplied population (or supplied units) multiplied by per capita water use (or unit water use). In the above investigations, water management has concentrated on adjustments to supply side of supply-demand equations, with major emphasis on modifying water supply.

On the other hand, the poor water management was pointed out and the need for developing water management system was stressed from the standpoints of regional economy (Tamaki, A., 1971, 1973; Shimazu, T., 1973; Hida, N., 1976; Hanayama, Y. and Fuse, T., 1977; Sueishi, T., 1978). Though the demand management through pricing policy is proposed in conjunction with supply management to solve water supply problem (Yasui, M., 1975), there is little detailed information about actual conditions of water use. In this respect, for water management in the river basin, it is strongly required to investigate the water demands in detail, especially the rapidly increasing industrial and municipal water demands.

1.2 General Characteristics of Water Resources System

A water resources system is a part of water system and consists of artificial water systems (Figure 1). It is the combination of structural facilities (reservoir, well, water distribution system and so on) and non-structural means (water law, water quality standard, price of water and so on), which transforms the inputs into the desired outputs.

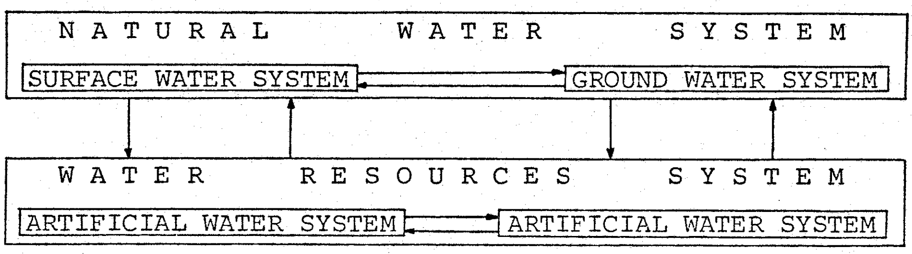


Figure 1 Natural and artificial water systems

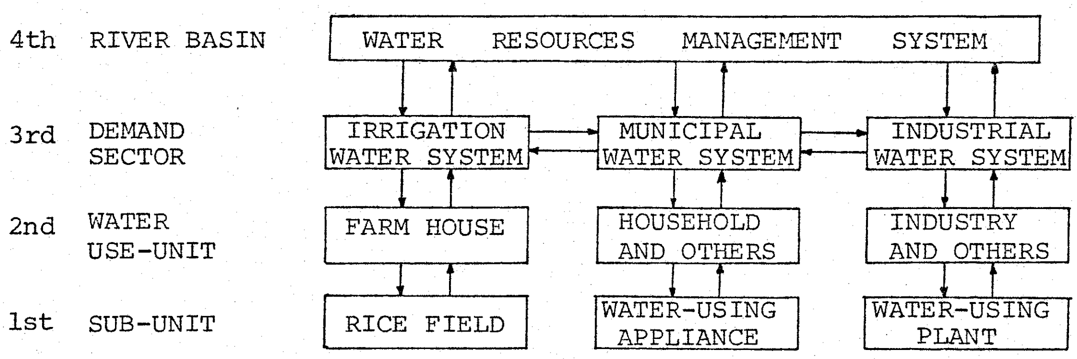
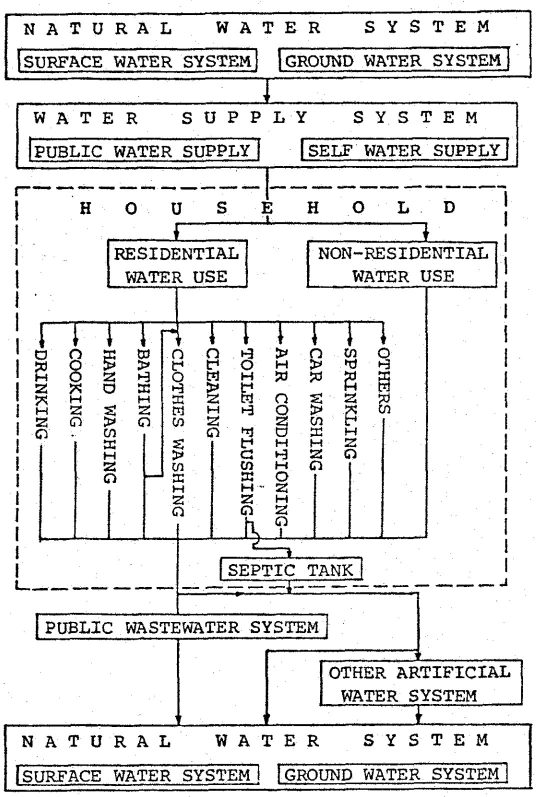


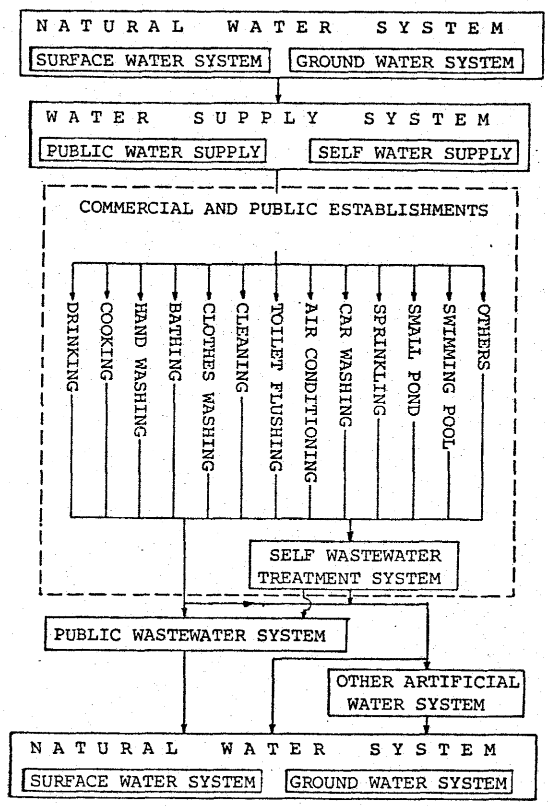
Figure 2 Multi-level water resources system

The water resources system in the river basin is obviously complex and is decomposed into various multi-level subsystems (Figure 2). The first or lowest level is sub-unit such as rice field, water-using appliance and plant. The second level is water use-unit or decision-making unit such as farm house, household, commercial and public establishments, and factory. The third level is water demand sector such as irrigation, municipal and industrial water systems, and the fourth or highest level is river basin as a water management unit.

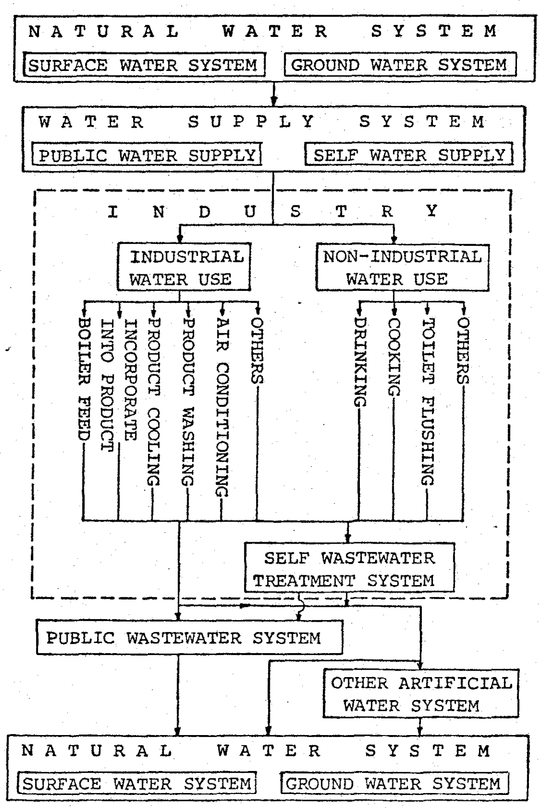
According to the purpose for which the water is used, it is classified into municipal, industrial, irrigation water uses and so on. Municipal water is the water supplied by municipal waterworks and used for urban activities, including residential, commercial, public and a part of industrial. Figure 3 represents schematically water uses in the water use-unit. Residential water is the water used in private residence and apartment house; it is divided into the domestic or indoor use and the outdoor use (Figure 3(a)). The former includes the water for drinking, cooking, washing, sanitary, bathing and so on. The latter represents the water for car washing, garden sprinkling and so on. Figure 3(b) shows the commercial and public water uses. The water used by commercial establishments (department store, restaurant, hotel, gas station and so no) is commercial water. Public water represents the water utilized in public



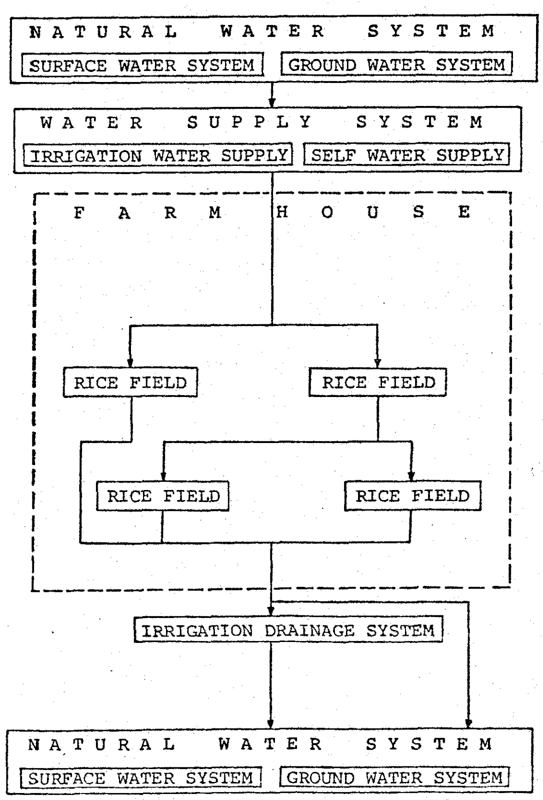
(a) Residential water use



(b) Commercial and public water uses



(c) Industrial water use



(d) Irrigation water use

Figure 3 Schematic representation of water uses facilities such as civic building, school and hospital. Industrial water represents the water used for industrial production and processing, and it is sometimes considered as a part of urban water (Figure 3(c)). Figure 3(d) illustrates the irrigation water use for crop production.

1.3 Previous Studies of Water Demands

Previous analytical studies of water demands are reviewed by the following sectors: residential, industrial, commercial and public. In briefly speaking, the majority of water demand analyses have been done for forecasting the future water requirements.

1.3.1 Residential Water Demand

Analysis of the residential water demand is focused on determining the demand functions. For residential water use, the following explanatory variables are used: the number of persons in household, income or income surrogate, the price of water, household technology, etc..

Table 1 summarizes several previous studies to estimate the elasticities of price, of income, and of household-size for residential demand according to the types of analysis and data. This table is obtained on adding Wong's review (Wong, S. T., 1972) to the results of the latest articles. There are two different types of analytical methods: cross-sectional (CS) and time series (TS). Data used for analysis

Table 1 Previous estimates of price, income and household-size elasticities

Type	Investigator	Year	Study area	Price elasticity	Income elasticity	Household-size elasticity
	Metcalf	1926	29 Waterworks systems	-0.65		
	Larson & Hudson,Jr.	1951	15 Illinois communities		0.70	
	Hanson & Hudson,Jr.	1956	8 Illinois communities		0.55	
	Seidel & Baumann	1957	American cities	-0.12 to -1.0		
	Fourt	1958	34 American cities	-0.39	0.28	
	Renshaw	1958	36 Water service systems	-0.45		
	Gottlieb	1963	Kansas	-0.66 to -1.24	0.28 to 0.58	
	Wong et al.	1963	Northeastern Illinois	0.01 to -0.72		
CS,AD	Gardner & Schick	1964	43 Northern Utah water systems	-0.77		
	Flack	1965	54 Western cities	-0.12 to -1.0		
	Bain et al.	1966	41 Californian cities	-1.10		
	Howe & Linaweaver	1967	39 Study areas, U.S.A.	-0.21 to -0.23	0.31 to 0.37	
	Conley	1967	24 Southern Californian commu.	-1.02 to -1.09		
	Turnovsky	1969	19 Massachusetts towns	-0.05 to -0.40		
	Wong	1970	4 Community size groups	-0.26 to -0.82	0.48 to 1.03	
	Willsie & Pratt*	1974	14 Seattle water use subdivisions		0.80	
	Morgan & Smolen*	1976	34 South. Californian cities	-0.43 to -0.65	0.24 to 0.67	
	Grunewald et al.*	1976	207 Kentucky rural districts	-0.50 & -0.92	0.20 & -0.14	0.55 & 0.33
	Darr et al.*	1976	28 towns, Israel	-0.13	0.65	
	Headley	1963	San Francisco-Oakland,1950-59.		0.00 to 0.40	
	Wong	1970	Chicago,1951-1961.	-0.02 to -0.28	0.20 to 0.26	
TS,AD	Young*	1973	Tucson,1946-64 & 1965-71.	-0.63 & -0.41		
	Sewell & Roueche*	1974	Victoria, Canada,1954-70.	-0.40		
	Darr et al.*	1976	Jerusalem, Israel,1954-68.		0.92	
	Grima*	1972	Toronto, Canada, 91 households	-0.93	0.56	0.59
	Morgan*	1973	Santa Barbara, 92 households		0.33 to 0.61	0.25 to 0.57
CS,ID	Darr et al.*	1976	Israel, 1892 households		0.18 to 0.60	
	Katzman*	1977	Penang, Malaysia, 1400 house.		0.00 to 0.39	
	Shimmi*	1977	Tachikawa, Japan, 250 house.		-0.01 to -0.02	0.51 to 0.59
	Gibbs*	1978	Maiami, 355 households	-0.51 & -0.62	0.51 & 0.81	
TS,ID	Morgan*	1974	Santa Barbara,34 house.,1967-72.	-0.49		
	Katzman*	1977	Penang,164 households,1970-75.	-0.1 to -0.2		

Note: CS: Cross-sectional TS: Time series AD: Aggregated data ID: Individual or household data
This table is obtained on adding Wong's review (1972) to the results of the latest studies (*).

are divided into two types: the aggregated data on municipalities or districts (AD) and the individual data on households (ID).

(a) Analyses of residential water demand on the basis of aggregated data

Most of the water demand analyses have been done by using the aggregated data on municipalities, because it is easy to gather data for analysis. These data, however, inevitably includes a part of industrial, commercial and public water uses.

On cross-sectional basis, several separate functions for residential water demand have been derived. Howe, C. W. and Linaweaver, F. P. Jr. (1967) estimated the separate demand functions for domestic and sprinkling uses for 39 study areas in the U.S.A.. The price elasticities were significantly greater for sprinkling than for domestic (-0.23 for domestic, -0.7 for sprinkling in the dry western areas, -1.6 for sprinkling in the humid eastern areas). The income elasticities were 0.35 for domestic, 0.4 for sprinkling in the western areas, and 1.5 for sprinkling in the eastern areas. Willsie, R. H. and Pratt, H. L. (1974) showed that the income elasticity was nearly 0.8 for single-family during both dry and wet seasons in the Seattle region. Morgan, W. D. and Smolen, J. C. (1976) indicated that the price elasticity was nearly -0.5 during both dry and wet seasons and the income elasticity was greater during wet season than during dry season (0.59 to 0.67 during wet season, 0.24 to 0.28 during dry season) in Southern California. Linaweaver, F. P. Jr., Beebe, J. C. and Shrivan, F. A. (see Howe, C. W. and Linaweaver, F. P. Jr., 1967), and Frankel, R. J. and Shouvanavirakul, P. (1973) indicated that water use was significantly affected by the factors such as type of rate structure (metered or non-metered), season of the year, and type of water service. Other cross-sectional studies indicated the price elasticity of 0.01 to -1.24 and the income elasticity of -0.14 to 1.03.

In the time series analyses, the time series data for price and income were deflated by using the consumer price index. The price elasticities lay in the range of -0.02 to -0.63 (Rees, J. A.: see Sewell, W. R. D. and Roueche, L., 1974; Wong, S. T., 1972; Young, R. A., 1973; Sewell, W. R. D. and Roueche, L., 1974). Hanke, S. H. (1970) indicated that both sprinkling and domestic demands were considerably reduced after meter installation in Boulder, Colorado. Willsie, R. H. and Pratt, H. L. (1974) showed that a significant decrease in water use occurred every year after the water rate increase, especially during the summer season in the Seattle region. The income elasticities were in the wide range of 0.00 to 0.92 (Headley, J. C.: see Wong, S. T., 1972; Wong, S. T., 1972; Darr, P., et al., 1976).

The cross-sectional and time series studies using the aggregated data lead to different results. It is very difficult to draw the generalizations on the basis of the obtained results.

(b) Analyses of residential water demand on the basis of individual data

Though the necessity for analysis by using individual data on households is fully recognized, it is not commonly done because of serious difficulty in obtaining data for individuals.

Grima, A. P. (1972) determined the price elasticity of -0.93 and the income elasticity of 0.56 from the cross-sectional data on 91 households in the Toronto region, and indicated that price was the most useful mean for residential water management.

Morgan, W. D. (1973, 1974) estimated the water demand functions by using cross-sectional data for winter on 92 residences, and time series data for 31 bimonthly billing periods on 34 residences in Santa Barbara. The income and household-size elasticities of domestic demand were in the ranges of 0.33 to 0.61, and of 0.25 to 0.57 from cross-sectional analysis. Price elasticity was -0.49 from time series analysis.

Darr, P., et al. (1975, 1976) investigated residential water use in Israel. For a sample of 1,892 residences, a significant portion of the variation in water use was explained by the variables of the number of persons in family, cultural origin, age of the head of household, and family income. Income elasticity ranged from 0.18 to 0.60.

Katzman, M. T. (1977) estimated the income and price elasticities in Penang Island, Malaysia. A cross-sectional analysis of 1,400 households indicated an income elasticity of nearly zero for low income families and of 0.2 to 0.4 for higher income families. A time series analysis of 164 individuals suggested a short-term price elasticity of -0.1 to -0.2.

In the earlier study, Shimmi, O. (1977) derived the water demand functions by using cross-sectional data on 250 households in Tachikawa city, Japan. He indicated the income elasticity of around zero and the household-size elasticity of 0.5 to 0.6.

The observations used for analysis are limited in number, except for the few studies (Darr, P., et al., 1975, 1976; Katzman, M. T., 1977). Grima (1972) and Morgan (1973) used the assessed sales value of residence as an income surrogate, and Katzman (1977) used three dummy variables representing four income categories owing to difficulty in obtaining income data.

1.3.2 Industrial, Commercial and Public Water Demands

Though the industrial, commercial and public water uses have been analyzed by several investigators, there is little information on the price sensitivity of demand.

Turnovsky, S. J. (1969) estimated the price elasticity for industrial of -0.5 to -0.9 from cross-sectional data of 19 towns in Massachusetts. De Rooy, J. (1974) showed that the price elasticities for cooling, processing and steam power were slightly less than unity from data of 30 large manufacturing plants in chemical and allied industries in the northern New Jersey. The National Commission on Water Quality in the U.S.A. showed the price elasticity for industrial: -0.7 for chemicals, -1.4 for paper, -1.4 for petroleum, and -1.6 for steel (see Lofting, E. M. and Davis, H. C., 1977). Wong, S. T. (1969) studied the actual condition of industrial water use in detail in the northern part of Illinois.

In Japan, Ota, I. (1961) investigated the regional difference in price of water by using the data on individual factories. Hida, N. (1969) illustrated the ways of ground water development for industry in the Gakunan district (southern foot of Mt. Fuji). Shimazu, T. (1971) studied the actual condition of water use in various manufacturing industries, and pointed out that there was notable difference in unit water use in m^3 per value of products shipped.

Asemann, K. and Wirth, H. (1974a, b) showed the wide difference in per capita use among the different types of establishments such as department stores, hotels, banks and government offices in Frankfurt am Main, West Germany. Lynne, G. D., et al. (1978) indicated that the price elasticities were -1.33 for department store, -0.93 for grocery store and supermarket, -0.12 to -0.24 for motel and hotel, and -0.17 for eating and drinking establishments from the data of 230 establishments in the Miami area, Florida.

1.4 Objective and Research Methodology of the Study

Though the need for demand management is emphasized for solving the water supply-demand problems in Japan as pointed out in the earlier section, there are few investigations of actual conditions of water use and the change of water demand structure on the basis of individual data. Furthermore, the most of previous studies of water demand, which are reviewed in the previous section, lead to widely different results taking no account of the above-mentioned differences in method and data for analysis.

Then, the objective of the study is to clarify the water demand structures for various sectors by using the aggregated and the individual data. The main stress is laid upon an analysis of residential water demand, its structure being remained to be vague in the previous studies, accounting for a large percentage of total municipal water use. The characteristics of variations in water use series are investigated by using time series data of different sectors. From the individual data obtained through the questionnaire survey, the relevant factors affecting water uses are identified, the separate demand functions for water are determined, and the income, price and household-size elasticities of demand for water are calculated. A comparison of the results in previous and the present studies is drawn, and the temporal change of residential water demand structure is discussed on the basis of the obtained results.

In this study, the Ashida river basin is selected for the following reason. This basin is typical one of the severe water-scarce areas in Japan. Water demands for industrial and municipal sectors have been rapidly increased with industrialization and urbanization since 1960. The Ministry of Construction (1973) forecasted the water shortage of about 200 million m^3/year in 1985 for the Bingo industrial district (including the middle and lower parts of the Ashida river basin).

Data on precipitation and stream discharge are provided by the branch office of the Ministry of Construction in Fukuyama. Various kinds of data on water use are supplied by several departments of government and municipal offices. The questionnaire survey is conducted to obtain data on socio-economic, technological and behavioral characteristics of water use-units by the writer. Data of water use series are obtained from the records of the municipalities for the fiscal years through 1975 to 1977.

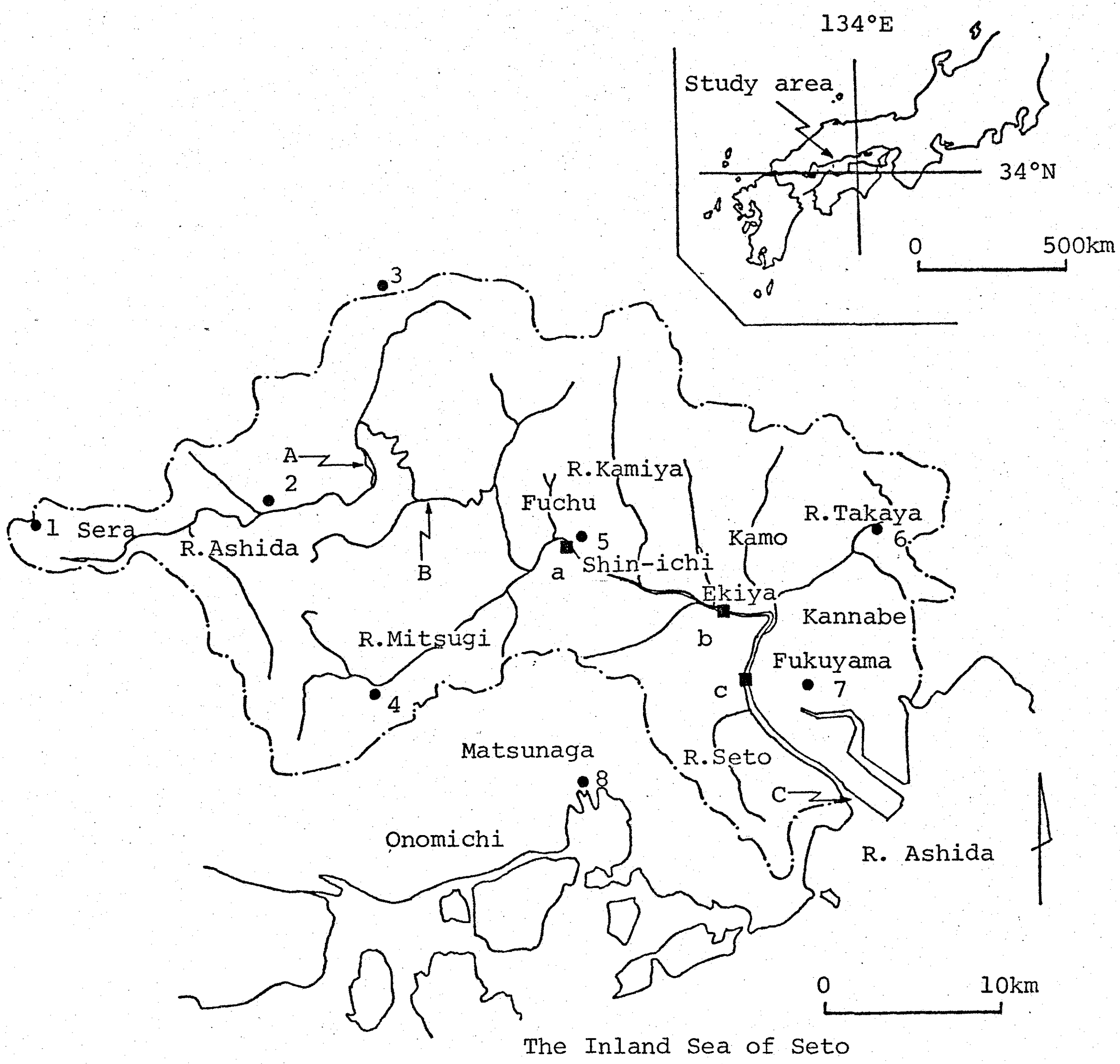
II DESCRIPTION OF THE STUDY AREA

2.1 General Conditions of the Ashida River Basin

The Ashida river basin is located in the eastern part of Hiroshima prefecture, with a drainage area of about 900 km^2 and a stream length of 90 km (Figure 4). The main river comes out of the Sera highlands and flows into the Inland Sea of Seto through the Fuchu, the Kannabe and the Fukuyama plains. The major tributaries of the river are the Mitsugi, the Kamiya, the Takaya and the Seto.

The Ashida river basin is divided into three parts: the upper, the middle and the lower basins. The upper basin is made up of highlands, the middle basin is composed of the Fuchu and the Kannabe plains, and the lower covers the area between the confluence of the Ashida and the Takaya rivers and the mouth of the Ashida river.

Table 2 gives the Ashida river basin and its environments for each sub-basin. Thirteen separate administrative districts lie entirely or partly within the Ashida river basin. They are four cities (Fukuyama, Fuchu, Mihara and Ibara) and nine towns (Yamato, Sera, Kui, Kozan, Jyoge, Sanwa, Mitsugi, Shin-ichi and Kannabe). Main part of Fukuyama city occupying the lower basin (except for Matsunaga, Ekiya, Kamo and Ashida) with a population of 250,000 is highly diversified industrial city noted especially for iron and steel. Fuchu (except for Kyowa)



A: Mikawa reservoir B: Hattabara reservoir (Under construction)
C: Ashida estuary reservoir

● Precipitation station ■ Gaging station

1. Sera 2. Kozan 3. Jyoge a. Fuchu
4. Mitsugi 5. Fuchu 6. Kannabe b. Moriwake
7. Fukuyama 8. Matsunaga c. Yamate

Figure 4 Location map of study area

Table 2 The Ashida river basin and its environments

	Upper river basin	Middle river basin	Lower river basin
Major tributaries	R. Yatada R. Utsudo R. Mitsugi R. Au	R. Kamiya R. Hattori R. Arichi R. Takaya	R. Seto
Topography	·Highlands ·Small basins	·Highlands ·Fuchu & Kannabe plains	·Highlands ·Fukuyama plain
Geology	Granite Rhyolite	Diorite Slate	Fluvial deposits
Administrative districts	Yamato* Mihara* Sera* Kui* Kozan Jyoge* Sanwa* Mitsugi Kyowa**	Fuchu(main) Shin-ichi Kamo*** Ekiya*** Ashida*** Kannabe Ibara*	Fukuyama(main, except Matsunaga)
Population in 1975	40 thousands	100 thousands	250 thousands
Leading industries	·Agriculture	·Agriculture ·Manufacturing industries	·Agriculture ·Manufacturing industries ·Commerce
Prominent land use	·Rice fields ·Dwellings	·Rice fields ·Dwellings ·Industrial facilities	·Rice fields ·Dwellings ·Industrial & commercial facilities
Water use facilities	·Mikawa dam(multi-purposes) ·Utsudo dam(hydropower) ·Irrigation reservoirs & intakes	·Irrigation reservoirs & intakes ·Municipal water supplies	·Irrigation reservoirs & intakes ·Municipal & industrial water supplies ·Ashida estuary reservoir (industrial)

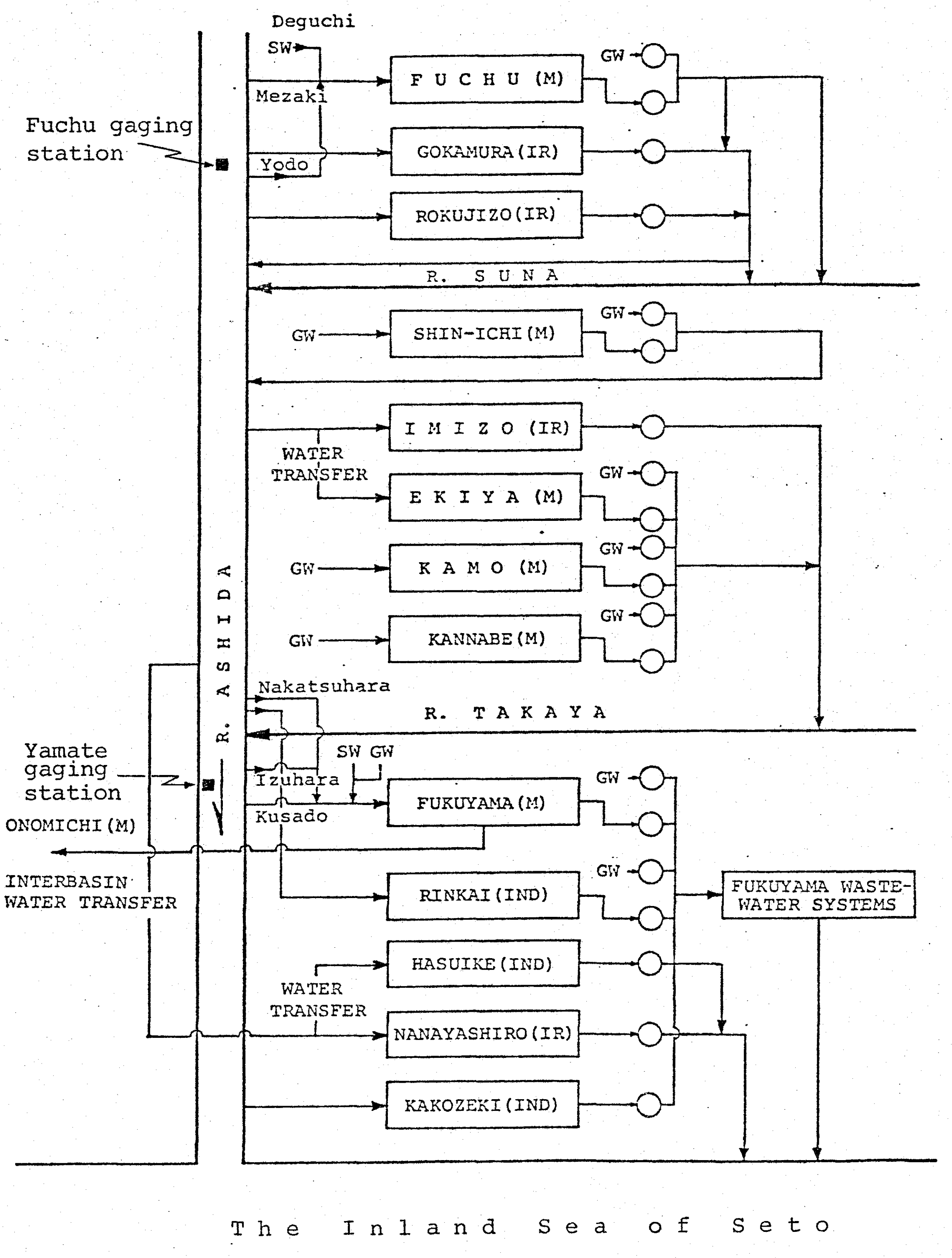
Note: * a part of the respective administrative districts
** a part of Fuchu city
*** a part of Fukuyama city

with a population of 50,000 is an industrial city noted for non-ferrous metal, furniture and fixtures. In Kannabe, textile goods and coated steel are produced, and other towns are characterized by agricultural industries.

In most of its documented history, the area has been dominated by agriculture both in areal extent and in population. Since a large part of the middle and the lower basins were designated as the Bingo industrial district in 1964, several large-scale manufacturing plants have been constructed and regional economy has quickly developed. In 1965, Fukuyama city (including Matsunaga) had a total population of 238,000 and industrial products of about 70 billion yen; in 1975 these rose to 330,000 and to 920 billion yen, respectively. Both municipal and industrial water demands for Fukuyama also showed the rapid increase from a total of 25 million m^3 in 1965 to 130 million m^3 in 1975.

Though water demands have rapidly increased, there are only two reservoirs in the basin (Figure 4). One is the Mikawa reservoir in the upper basin. The other is the Ashida estuary reservoir at the mouth of the river.

Figure 5 schematically represents the water resources systems in the middle and lower parts of the basin for 1977. Most of supply sources lie in the reach between the Fuchu and the Yamate gaging stations. Four irrigation water supplies (Gokamura, Rokujizo, Imizo and Nanayashiro),



IR: Irrigation water supply
M : Municipal water supply
IND: Industrial water supply

SW: Surface water
GW: Ground water
○: Use unit

Figure 5 Schematic representation of water resources system in the Ashida river basin two municipal water supplies (Fukuyama and Fuchu) and two industrial water supplies (Rinkai and Kakozeki) obtain their water from the Ashida river and the tributaries. The Hasuike industrial and the Ekiya municipal water supplies are transferred from the Nanayashiro and the Imizo irrigation districts, respectively. Other municipal waterworks utilize the ground water.

The quantities of water utilized by sectors are listed in Table 3. A total of maximum water right permitted by River Law is 8.91 m^3/sec, and the amount of ground water pumped for municipal and industrial purposes is roughly estimated as 1.00 m^3/sec. For agricultural purpose, it is not clear.

In the urban area of Fukuyama city, industrial, residential, and commercial and public sectors utilized

Table 3 Actual water use in the Ashida river basin for 1977

	Surface water	Ground water	Others
Irrigation water use	4.78 (14)	*	Irrigation reservoirs
Municipal water use	1.70 (5)	1.00** (3) (Municipal and Industrial combined)	
Industrial water use	2.43 (7)		Irrigation water
T o t a l	8.91 (26)	*	

Note: * not clear ** roughly estimated value
The upper row values represent water use in m^3/sec.
The lower values in parentheses represent water use divided by the drainage area in mm/month.
Data are provided by the branch office of the Ministry of Construction in Fukuyama.

73 %, 19 %, and 8 % of total water use of 21 million m^3 during two months of August and September in 1977, respectively. In spite of water shortage in the basin, the maximum amount of 15,000 m^3/day is transferred from Fukuyama to Onomichi cities situated on the outside of the basin.

Waste discharge from each system in the middle basin returns to the Ashida river via its tributaries and irrigation canals. In the lower basin, it does not return to the Ashida river, but to the Inland Sea of Seto. Highly polluted water is recognized in the tributaries such as the Suna, the Takaya, and the Seto rivers (Figure 5). Fukuyama municipal waterworks, therefore, obtains water from the Nakatsuhara source which stands above the confluence of the Takaya river. Polluted water is also found in the lower parts of the Nanayashiro irrigation canals.

2.2 Water Resources in the Ashida River Basin

In general model for water balance of river basin, the following equations are given.

$$P - Ea - D_S - D_G - D_A - \Delta S = 0 \quad \text{.......................(1)}$$

$$P - Ea - Ws = 0 \quad \text{.................................(2)}$$

where P is precipitation, Ea actual evapotranspiration, D_S stream water discharge, D_G ground water discharge, D_A discharge of artificial water system (non-return flow), ΔS change in water storage of the river basin, and Ws water surplus.

There are eight precipitation stations and three gaging stations which offer long-term data (Figure 4). Mean annual precipitation (1946-1975) in the basin differs from station to station, decreasing from west to east: 1,498 mm in Sera, 1,334 mm in Fuchu and 1,260 mm in Fukuyama. The mean precipitation on the basin for each month (P) is determined by arithmetic mean method from data for eight stations. Actual evapotranspiration (Ea) is given by 70 % of potential evapotranspiration determined by Penman's method (Ichikawa, M., 1973; Kayane, I., 1973). Data needed for estimating potential evapotranspiration can be obtained only from the Matsunaga station for 1941 to 1970 (Japan Meteorological Agency, 1972). Stream discharge (D_S) can be obtained from the Yamate station for 1963 to 1975. Ground water discharge (D_G) can be neglected, because the amount of ground water through the valley section near the Yamate gaging station was calculated as 600 m^3/day (0.3 mm/year) by Yamamoto, S. (1965). The sum of discharge of artificial water system (D_A) and change in storage of the river basin (ΔS) is given as residual.

Table 4 lists water balance of the Ashida river basin. There are some differences in the period of hydrological time series data, but the values can be compared with acceptable accuracy. Annual precipitation (P), actual evapotranspiration (Ea), and water surplus (Ws) account for averages of 1,362 mm, 634 mm and 728 mm, respectively.

Because change in storage (ΔS) can be neglected for long time period, discharge of artificial water system (D_A) accounts for average of 126 mm/year.

Water surplus (Ws) is considered as the amount of potential water resources (Sekiguchi, T. and Yoshino, M. M., 1953; Kayane, I., 1969). Water surplus is separated into the two elements: direct flow and base flow. Base flow is the outflow from ground water which may be used without the construction of reservoir. For water supply-demand management, it is required to evaluate the quantity and the variability of supply sources in each month. The available stream water is defined as minimum flow for each month (Figure 6). Figure 7 represents monthly changes of total discharge (D_F) and minimum discharge (D_{MF}) at the Fuchu station, which is above most of intakewires, for 1962 to 1975.

Table 4 Water balance of the Ashida river basin

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
P	54	55	83	124	126	205	223	107	182	94	65	44	1 362
Ea	20	25	41	59	75	77	90	94	66	43	25	19	634
Ws	34	30	42	65	51	128	133	13	116	51	40	25	728
D_S	21	21	26	53	49	77	146	43	85	40	22	19	602
D_G	0	0	0	0	0	0	0	0	0	0	0	0	0
$D_A+\Delta S$	13	9	16	12	2	51	-13	-30	31	11	18	6	126

Note: P: Precipitation for 1946-1975.(*)
Ea: Actual evapotranspiration for 1941-1970.(**)
Ws: Water surplus.
D_S: Stream water discharge at the Yamate gaging station for 1963-1975.(*)
D_G: Ground water discharge calculated by Yamamoto, S.(1965).
D_A: Discharge of artificial water system.
ΔS: Change in storage of the river basin.
Unit in mm.
Data are provided by the branch office of the Ministry of Construction (*), and by Japan Meteorological Agency (1972)(**).

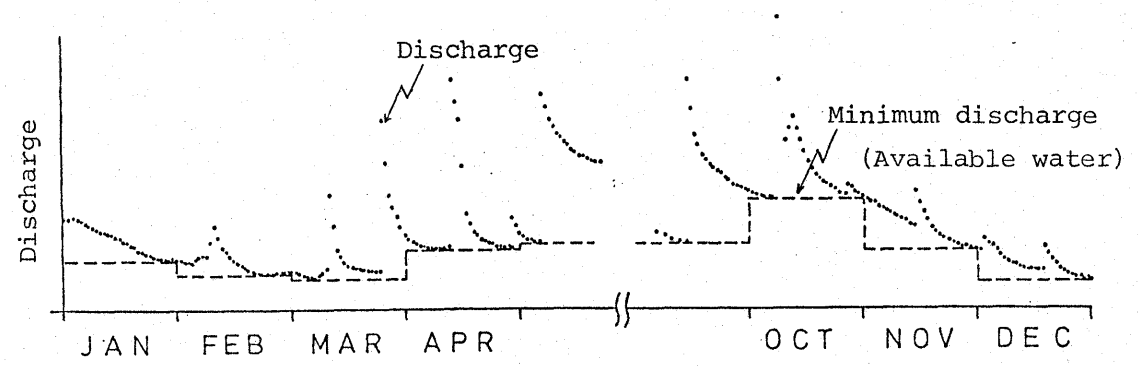


Figure 6 Definition of available water for each month

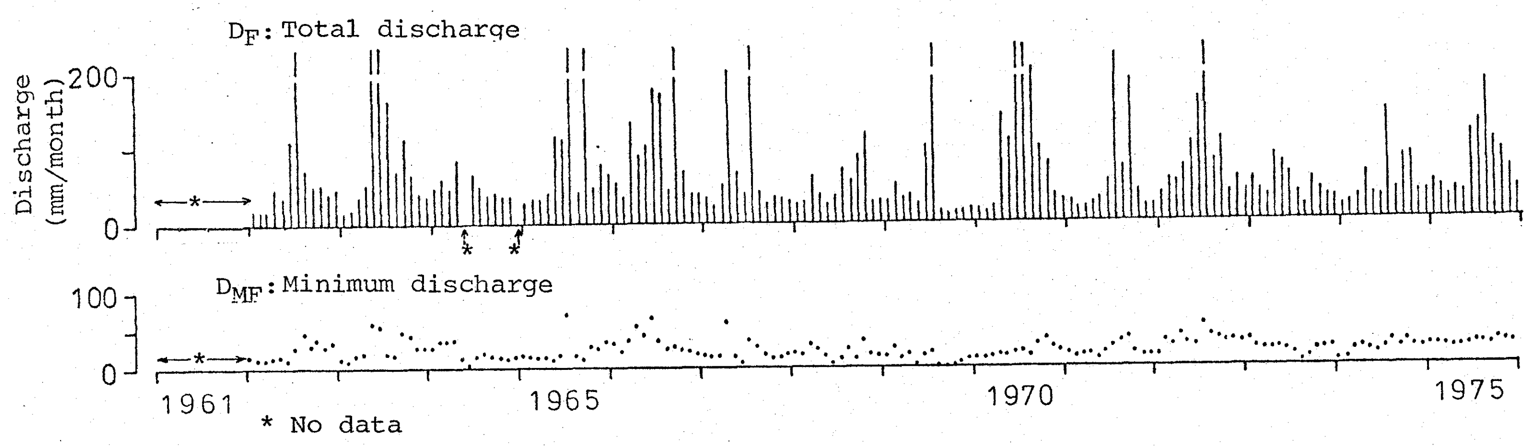


Figure 7 Monthly changes of total and minimum discharges at Fuchu station

Table 5 gives the mean values and the standard deviations of total and minimum discharges at the Fuchu station. Mean value of minimum discharge (D_{MF}) varies from 19 mm/month to 29 mm/month, and the standard deviations of minimum discharge are greater during the irrigated period than during the non-irrigated period. Sugawara, M. (1971) indicated that the variation of lower stream flow was greater in the western Japan than in the eastern Japan. Minimum discharge accounts for 278 mm/year and constitutes about 32 % of total discharge of 882 mm/year.

The productive aquifer lies in the Kannabe plain and is composed mainly of coarse sands and gravels, with thickness of 20 m. In the Fukuyama plain, with the development of ground water by industrial sector and subsequent lowering of the ground water table, the seaward flow of ground water had been decreased, permitting sea water to intrude into usable parts of the aquifer. Ground water is the supplemental supply source in the river basin.

Table 5 Discharge at the Fuchu gaging station for 1962-1975

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
D_F	32 (13)	32 (14)	42 (28)	72 (46)	82 (77)	120 (89)	201 (106)	69 (54)	104 (74)	57 (27)	38 (17)	35 (12)	882 (281)
D_{MF}	19 (8)	19 (8)	22 (8)	27 (14)	21 (14)	22 (17)	29 (16)	23 (12)	24 (13)	27 (12)	22 (8)	23 (8)	278 (72)

Note: D_F: Total discharge at the Fuchu gaging station for 1962-1975.
D_{MF}: Minimum discharge at the Fuchu gaging station for 1962-1975.
Values in parentheses represent the standard deviations.
Unit in mm.
Data are provided by the branch office of the Ministry of Construction in Fukuyama.

2.3 Past Solutions of Water Supply-Demand Problems in the Ashida River Basin

There are several means to solve the water supply and demand problems. In the present section, the past solutions of water supply-demand problems adopted in the Ashida river basin are described.

Figure 8 shows the past water management in the Ashida river basin after the second World War. Past means for solving water problems are classified into two types: (1) modification of water supply, and (2) modification of water demand. The former contains three means: the development of stream water without the construction of reservoir, water transfer from agricultural to non-agricultural sectors, and the development of stream water through the construction of reservoir. The latter presents the restriction on water use under drought conditions.

(1) Modification of water supply

The Mikawa reservoir for irrigation purpose was constructed by the Ministry of Agriculture and Forestry in 1960, because drought often occurred and rice crop production received great damage. It had an effective storage capacity of 8.8×10^6 m^3 and the planned irrigated area of 3083.7 ha..

In 1953, 1961 and 1963, the rapidly growing industrial and municipal sectors obtained water by giving compensations

(Year)	1950	55	60	65	70	75

River law: 1895 ← Old River Law → 65 ← New River Law →

River manager: ← Hiroshima prefectural government → 67 ← Ministry of Construction →

Gradual decrease in irrigation water demand (1955–1964); Rapid increases in municipal and industrial water demands (1965–1977)

1 Modification of supply

a) Development of stream water without reservoir
- 53 Fukuyama(M)
- 61 Rinkai(IN)
- 63 Fukuyama(M)
- 69 Provisional water right

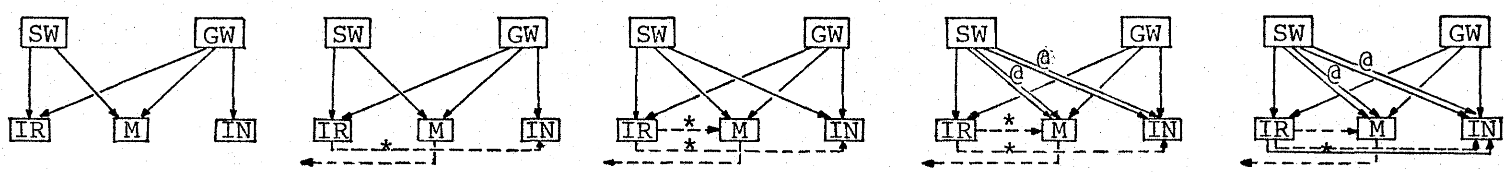
b) Water transfer from irrigation water
- 58 Hasuike(IN)*
- 63 Ekiya(M)*
- 73 Increase in storage capacity of Mikawa reservoir(IN)**
- 76 Re-allocation of storage capacity of Mikawa reservoir(M)**

c) Development of stream water through the construction of reservoir
- 60 Mikawa reservoir(IR)
- 77 Ashida estuary reservoir(IN)
- Hattabara reservoir(M)***

2 Modification of demand
- 73 Water allocation under drought condition

Water right (m^3/sec)	Year	1960	1965	1970	1975	1977
	IR(Irrigation water use)	#	5.403+#	7.101	7.101	4.780
	M(Municipal water use)	0.075	0.492	0.492+0.442@	0.492+1.170@	1.551+0.232@
	IN(Industrial water use)	*	0.81 ++*	0.081+1.273@ ++*	2.778+1.620@ ++*	3.473+0.926@ ++*

Water resources allocation



Note: * Water transfer restricted by River Law ** Water transfer permitted by River Law *** Under construction
Custom water right permitted by River Law @ Provisional water right permitted by River Law
SW: Stream water GW: Ground water IR: Irrigation water M: Municipal water IN: Industrial water

Figure 8 Water management in the Ashida river basin to the existing water users without the construction of reservoir. Furthermore, the Hasuike industrial water supply purchased the maximum amount of 20,000 m^3/day from the Nanayashiro irrigation district after 1958. In 1963, the Ekiya municipal water supply was transferred from the Imizo irrigation district. Water transfer is permitted only by special admission of the water manager under the old and the present River Law. The above two cases were not permitted by water manager.

Both industrial and municipal sectors often withdrew more water than the quantity of water permitted by River Law. Though the Ministry of Construction as a water manager had the principle that the water right was given to demand sectors with an available supply source, it did not take the strong measure to stop withdrawing. In 1969, the water manager was unwilling to give a permission of withdrawal on condition of developing new supply source and giving priority to the existing water users. Such water right is so called "provisional water right". In 1975, the provisional water right accounted for 2.79 m^3/sec, representing about a half of total water right of 6.06 m^3/sec for municipal and industrial. A total of water right for all sectors accounted for 13.171 m^3/sec (37.9 mm/month representing the water right divided by the drainage area) during the irrigation period through June to September. It exceeded significantly the mean value of minimum discharge of 22 to 29 mm/month (Table 5).

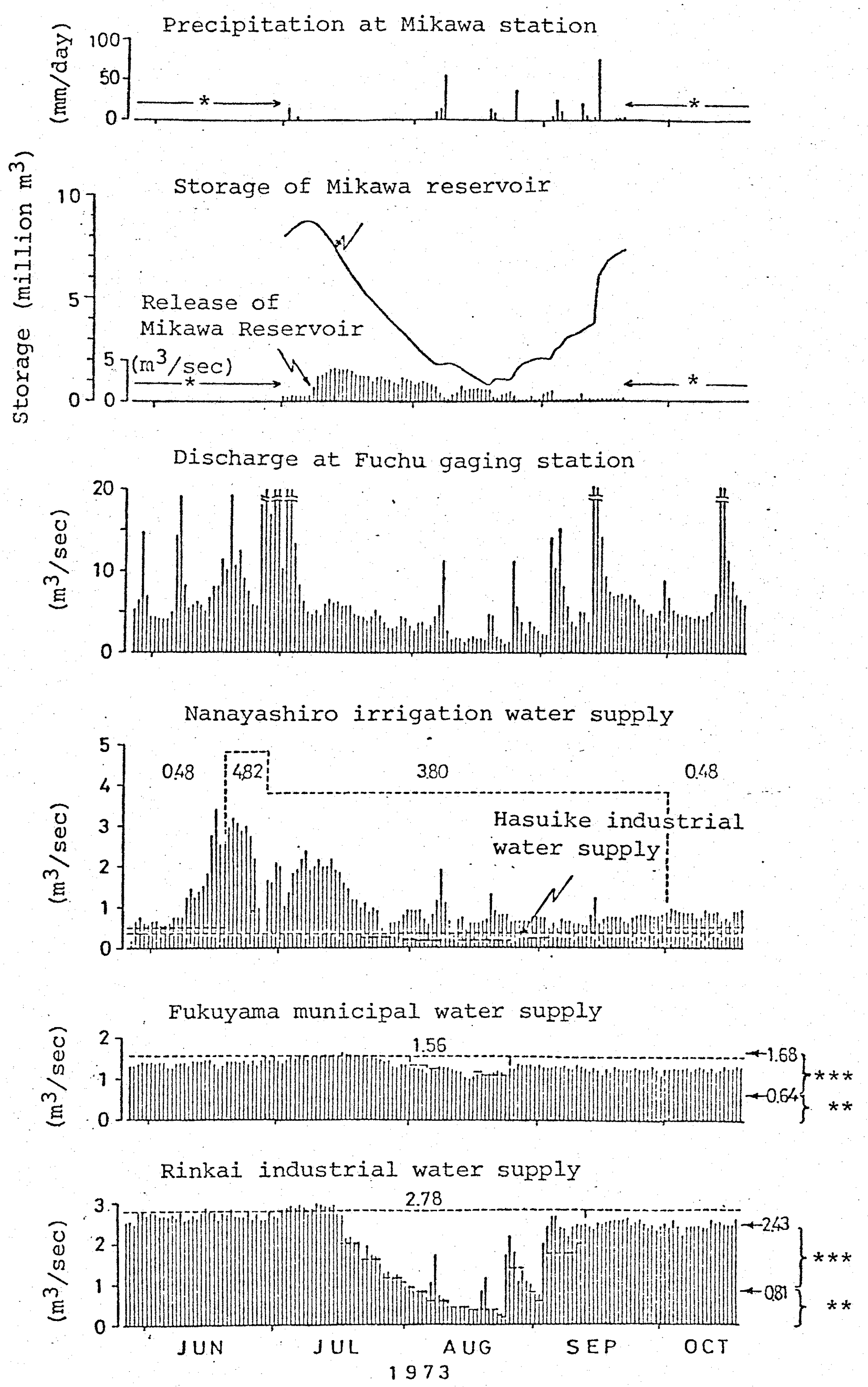
In 1973, the storage capacity of the Mikawa reservoir was increased by 3.35×10^6 m^3. The additional work enabled the Rinkai industrial water supply to obtain a regular water right of 0.695 m^3/sec. In 1976, water transfer was done from agricultural to municipal sectors. Municipal sector obtained a storage capacity of 5.38×10^6 m^3 and a total of regular water right of 1.059 m^3/sec. Both cases in 1973 and 1976 were the pioneering work permitted on legal basis.

In 1977, the Ashida estuary reservoir with an effective storage capacity of 5×10^6 m^3 was completed at the mouth of the river. The regular water right was given at 1.968 m^3/sec for industrial. Though a large quantity of water was transferred, the municipal and industrial sectors have even now the provisional water right of 1.158 m^3/sec. The Hattabara reservoir with an effective storage capacity of 60×10^6 m^3 is under construction in the upper basin, and it takes more years to complete. The unit cost of water storage continues to increase rapidly. It becomes difficult to solve the water supply-demand problem by increasing supply through the construction of gigantic reservoirs.

(2) Modification of water demand

It is very important for water management to allocate water to various sectors under drought conditions. Most of water users in the basin experienced a severe drought in summer of 1973. The concerned users and municipal offices organized themselves into committee on water allocation. The Ministry of Construction as water manager did not participate in this committee.

Figure 9 shows the conditions of water allocation under drought in 1973. The storage of the Mikawa reservoir decreased to only 7×10^5 m^3 in August 19. The Nanayashiro irrigation and the Rinkai industrial water supplies drastically reduced the amount of withdrawals. For Fukuyama municipal water supply, a striking decrease in withdrawal was not found. Though the agricultural sector was given a priority over other sectors, it transferred the priority to municipal. The factory producing iron and steel received a great damage on account of restriction on water use.



←*→ Data missing

** Regular water right

*** Provisional water right

Figure 9 Water resources allocation under drought condition in 1973

III ANALYSIS OF TIME SERIES OF WATER USE

A time series record provides useful information on past water use and water management in the future. The objective of the present chapter is to analyze the water demand structures by using the time series data of water use for demand sectors. In the first section, the water demand functions are determined from the annual data of water use and socio-economic factors. In the second section, the seasonal and daily variations of water use series are clarified.

3.1 Analysis of Annual Series of Water Use

The amount of water used for industrial and municipal is influenced by factors such as the number of water use-units, the industrial products, the consumer or business income, the price of water, the technological conditions, and the physical conditions.

Here, to evaluate the effects of the above factors on water use, the following two water demand models are tested using linear and log-linear equations.

Model A

$$Y = a_0 + a_1X_1 + a_2X_2 \quad \text{......(3)}$$

Model B

$$\log Y = b_0 + b_1\log X_1 + b_2\log X_2 \quad \text{......(4)}$$

$$\text{or } \log Y = b_0 + b_1\log X_1 + b_2X_2 \quad \text{......(5)}$$

where Y is the annual water use, X_1 variable associating with the size of activities such as the number of use-units and the industrial product, and X_2 the price of water or the dummy variable representing the effect of drought on water use.

The water demand functions are determined for the following sectors which offer available annual series data of water use and other variables. They are: (1) Fukuyama municipal water use (total), (2) Fukuyama industrial water use (sum of Rinkai and Hasuike industrial water uses), (3) Fukuyama industrial water use (only Rinkai industrial water use), (4) Fuchu municipal water use (total and parts of municipal water use). Fuchu municipal water use is divided into five groups: residential; commercial (except for civic building, school, hospital, bank and hotel); civic building and school; manufacturing industry; hospital, bank and hotel.

The combinations of variables and the period of records are given in Table 6. In this table, WU is annual water use, NM the number of metered units, NS the number of use-units, IP the industrial product deflated by using the wholesale price index (100 for 1970), PDC the price of water deflated by using the consumer price index (100 for 1970), PDW the price of water deflated by the wholesale price index. The wholesale and consumer price indices are obtained through "A charted survey of Japan" (Yano, I., 1978).

Table 6 Variables and the period of records

$Y = f(X_1, X_2)$

Model A: $Y = a_0 + a_1 X_1 + a_2 X_2$

Model B: $\log Y = b_0 + b_1 \log X_1 + b_2 \log X_2$ (X_2: PDC, PDW)

$\log Y = b_0 + b_1 \log X_1 + b_2 X_2$ (X_2: D)

	Y	X_1			X_2			Records available
	WU	NM	NS	IP	PDC	PDW	D	
Fukuyama municipal Total	($10^6 m^3$/year)	(10^6)	(10^6)	-	(yen/m^3)	-	-	1960-1976
Fukuyama industrial Rinkai & Hasuike	($10^6 m^3$/year)	-	-	Total (10^9yen/year)	-	(yen/m^3)	0: 1965-72 1: 1973-76	1965-1976
Fukuyama industrial Rinkai	($10^6 m^3$/year)	-	-	Iron & steel (10^9yen/year)	-	(yen/m^3)	0: 1965-72 1: 1973-76	1965-1976
Fuchu municipal Total	($10^5 m^3$/year)	(10^2)	-	-	(yen/m^3)	-	-	1966-1976
Residential	($10^5 m^3$/year)	(10^2)	-	-	(yen/m^3)	-	-	1966-1976
Commercial#	($10^4 m^3$/year)	(10^1)	-	-	-	(yen/m^3)	-	1966-1976
Civic building & school	($10^3 m^3$/year)	(10^0)	-	-	-	(yen/m^3)	-	1966-1976
Manufacturing industries	($10^3 m^3$/year)	(10^0)	-	-	-	(yen/m^3)	-	1966-1976
Hospital, bank & hotel	($10^3 m^3$/year)	(10^0)	-	-	-	(yen/m^3)	-	1966-1976

Note: WU: water use NM: the number of metered units NS: the number of use-units

IP: industrial product deflated by the wholesale price index (100 for 1970)

PDC: the price of water deflated by the consumer price index (100 for 1970)

PDW: the price of water deflated by the wholesale price index (100 for 1970)

D: dummy variable of drought effect on water use (0: 1965-1972, 1: 1973-1976)

except for civic building, school, hospital, bank and hotel

In summer of 1973, water users in the river basin experienced severe drought as illustrated in the previous chapter, and D is dummy variable representing the effect of drought on water use (0 for 1965-1972, 1 for 1973-1976). The data of consumer and business income are not available.

Tables 7 and 8 give the regression analysis by using linear equation (3), and by using log-linear equation (4) or (5), respectively. For all of sectors with the exception of (4-f) hospital, bank and hotel (a part of Fuchu municipal water use), a large portion of the variation in annual water use can be explained by the variables of the number of metered units (NM) or use-units (NS), or the industrial product (IP). The coefficient of the deflated price of water (PDC and PDW) differs significantly from zero at the 5 percent level in the only case of (1) Fukuyama municipal water use. In general, the change in price of water does not significantly affect the amount of water used on the aggregated level. The coefficients of D, representing the effect of drought on water use, are negative values and significantly differ from zero at the 5 % level for (2) Fukuyama industrial water use (Rinkai and Hasuike), and for (3) Fukuyama industrial water use (Rinkai).

Figure 10 illustrates the observed values of annual water use and the values calculated from the respective demand equations for demand sectors (Tables 7 and 8). In the cases of Fukuyama industrial water uses (Figure 10

Table 7 Regression analysis using linear equation (Model A)

Model A $Y = a_0 + a_1 X_1 + a_2 X_2$

	a_0	a_1			a_2			R	F	d.f.
		NM	NS	IP	PDC	PDW	D			
(1) Fukuyama municipal Total	-1.466	0.682** (30.37)			-0.141¢ (2.11)			.991	492.53**	14
	5.497		0.511** (20.00)		-0.254* (2.48)			.984	213.71**	14
(2) Fukuyama industrial Rinkai & Hasuike	3.743			0.224** (10.31)			-43.873** (5.27)	.971	73.89**	9
(3) Fukuyama industrial Rinkai	11.437			0.287** (8.20)			-36.537** (3.76)	.958	50.80**	9
(4) Fuchu municipal (a) Total	-5.089	0.407** (27.55)						.994	758.82**	9
(b) Residential	-2.586	0.224** (17.66)			-0.001 (0.05)			.993	274.34**	8
(c) Commercial#	-15.32	1.064** (8.52)						.943	72.53**	9
(d) Civic building & school	-128.051	4.113** (10.75)						.963	115.66**	9
(e) Manufacturing industries	17.197	4.271** (12.45)				-0.158 (0.25)		.976	81.56**	8
(f) Hospital, bank, hotel	4.354	1.642** (3.56)				-0.297 (0.56)		.798	7.01*	8

Note: a_i: the regression coefficient the value in parenthesis: t-value
R: the multiple correlation coefficient F: the variance ratio d.f.: the degrees of freedom
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
¢ Significantly different from zero at the 10 percent level.
WU: water use NM: the number of metered units NS: the number of use-units
IP: industrial product deflated by the wholesale price index (100 for 1970)
PDC: the price of water deflated by the consumer price index (100 for 1970)
PDW: the price of water deflated by the wholesale price index (100 for 1970)
D: dummy variable of drought effect on water use (0: 1965-1972, 1: 1973-1976)
\# except for civic building, school, hospital, bank and hotel

Table 8 Regression analysis using log-linear equation (Model B)

Model B

$$\log Y = b_0 + b_1 \log X_1 + b_2 \log X_2 \qquad (X_2: \text{PDC, PDW})$$

$$\log Y = b_0 + b_1 \log X_1 + b_2 X_2 \qquad (X_2: \text{D})$$

	b_0	b_1			b_2			R	F	d.f.
		NM	NS	IP	PDC	PDW	D			
(1) Fukuyama municipal Total	-0.653	1.416** (23.32)			-0.205 (1.12)			.988	280.75**	14
	-0.187		1.288** (23.10)		-0.429* (2.30)			.988	275.49**	14
(2) Fukuyama industrial Rinkai & Hasuike	1.018			1.166** (8.34)			-0.255* (2.90)	.953	44.17**	9
(3) Fukuyama industrial Rinkai	0.134			0.777** (7.57)		-0.193 (0.20)		.933	30.37**	9
	-0.205			0.905** (8.57)			-0.215¢ (2.02)	.954	45.93**	9
(4) Fuchu municipal (a) Total	-1.408	1.526** (36.74)						.997	1349.99**	9
(b) Residential	-1.739	1.588** (32.73)			-0.008 (0.07)			.998	942.28**	8
(c) Commercial#	-1.074	1.550** (12.35)						.972	152.58**	9
(d) Civic building & school	-1.773	2.154** (10.37)						.961	107.63**	9
(e) Manufacturing industries	1.294	0.795** (5.80)				-0.211 (0.18)		.899	16.91**	8
(f) Hospital, bank & hotel	0.035	1.346* (2.94)				-0.275 (0.25)		.731	4.58¢	8

Note: b_i: the regression coefficient; the value in parenthesis: t-value
R: the multiple correlation coefficient; F: the variance ratio; d.f.: the degrees of freedom
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
¢ Significantly different from zero at the 10 percent level.
except for civic building, school, hospital, bank and hotel.

(1) Fukuyama municipal water use

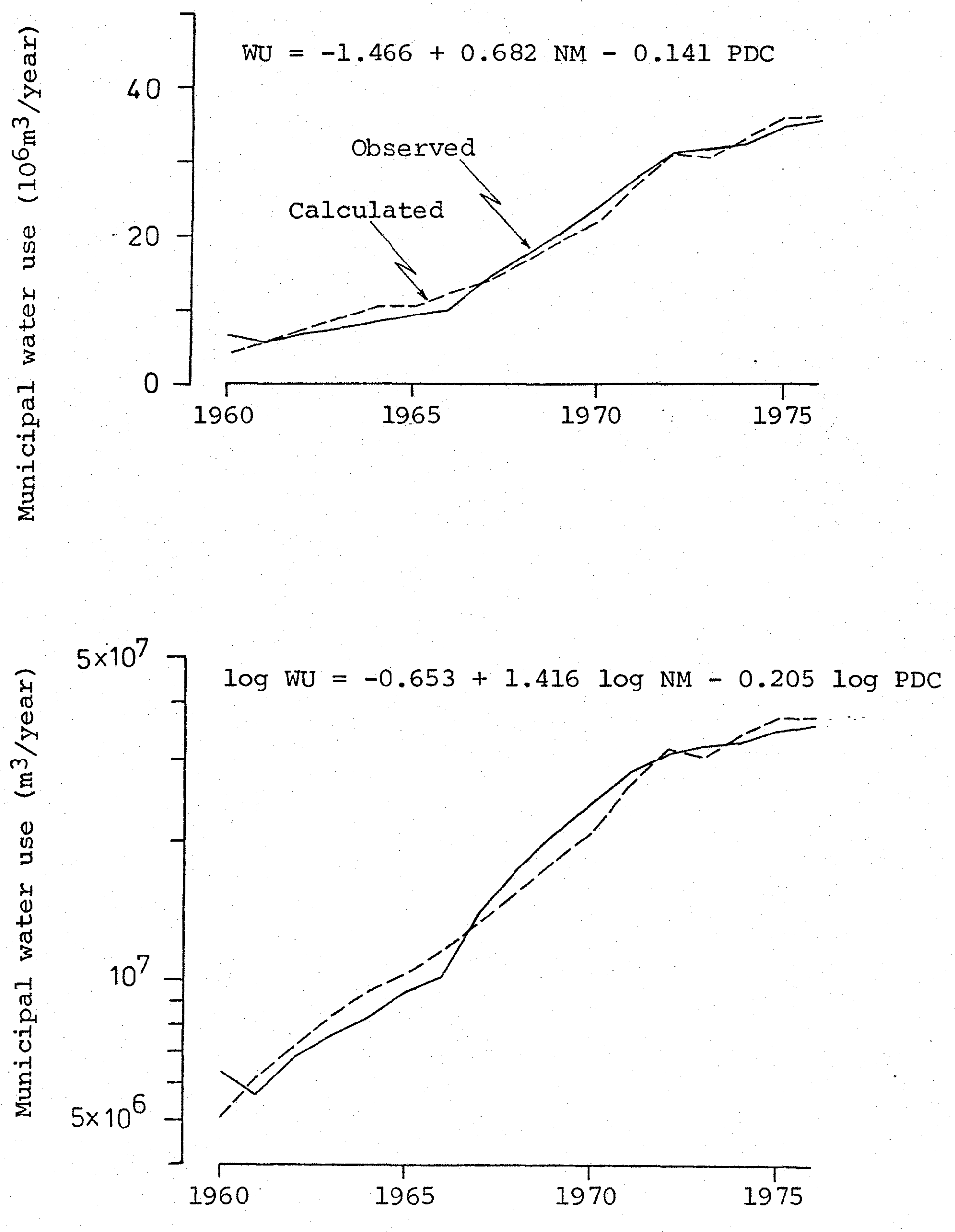


Figure 10 The observed values and the calculated values of annual water use

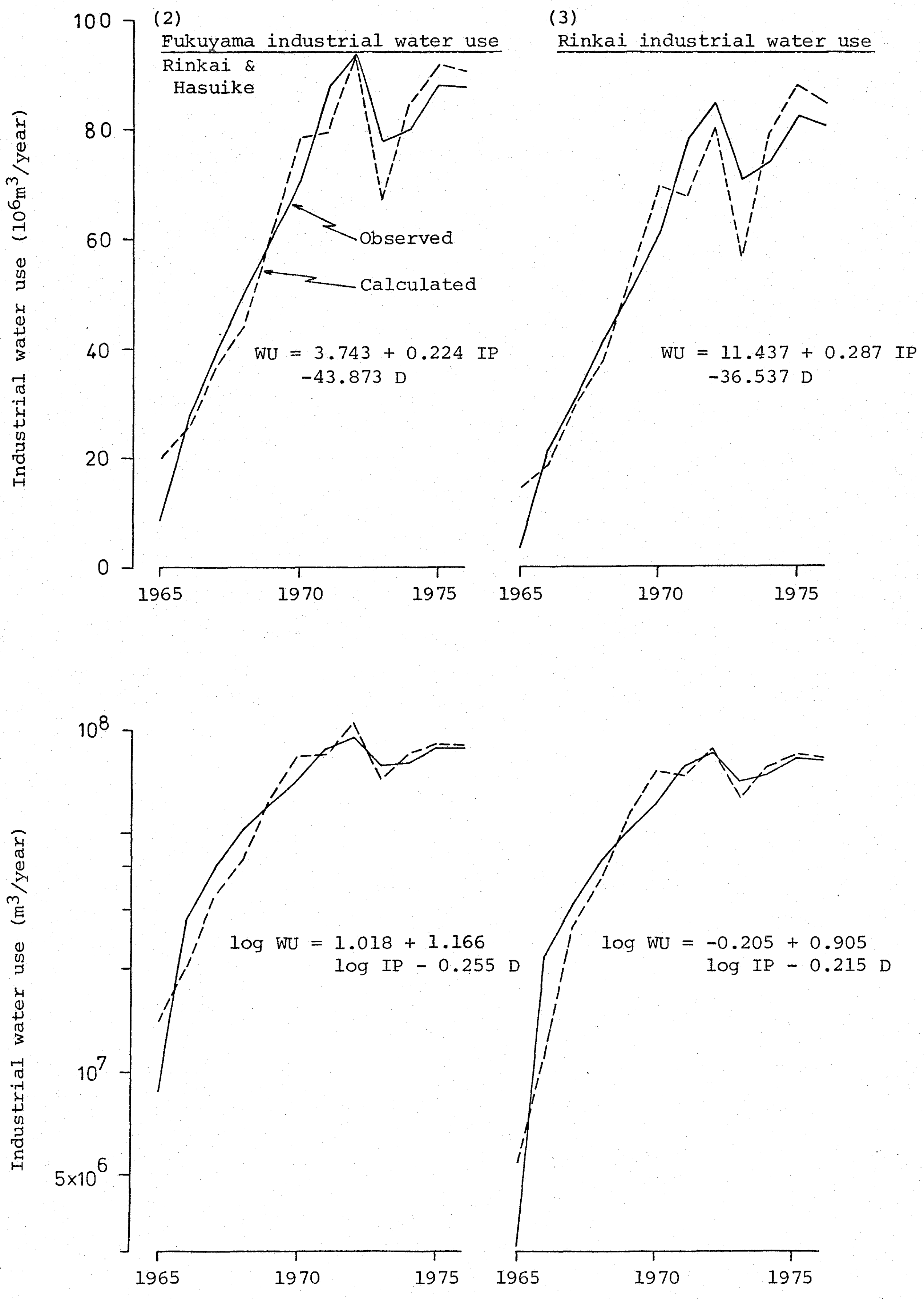


Figure 10 (continued)

(4) Fuchu municipal water use

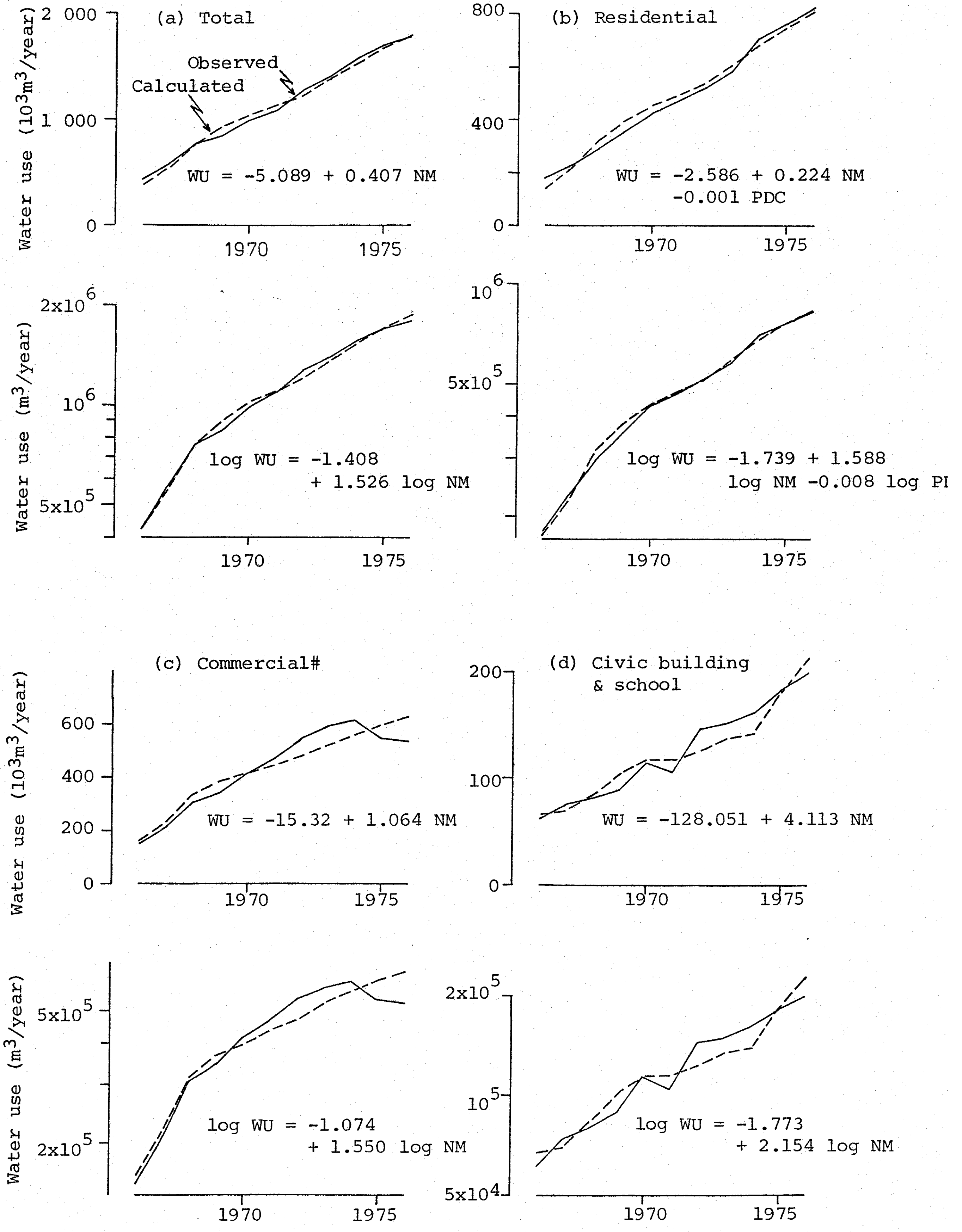


Figure 10 (continued)

(4) Fuchu municipal water use

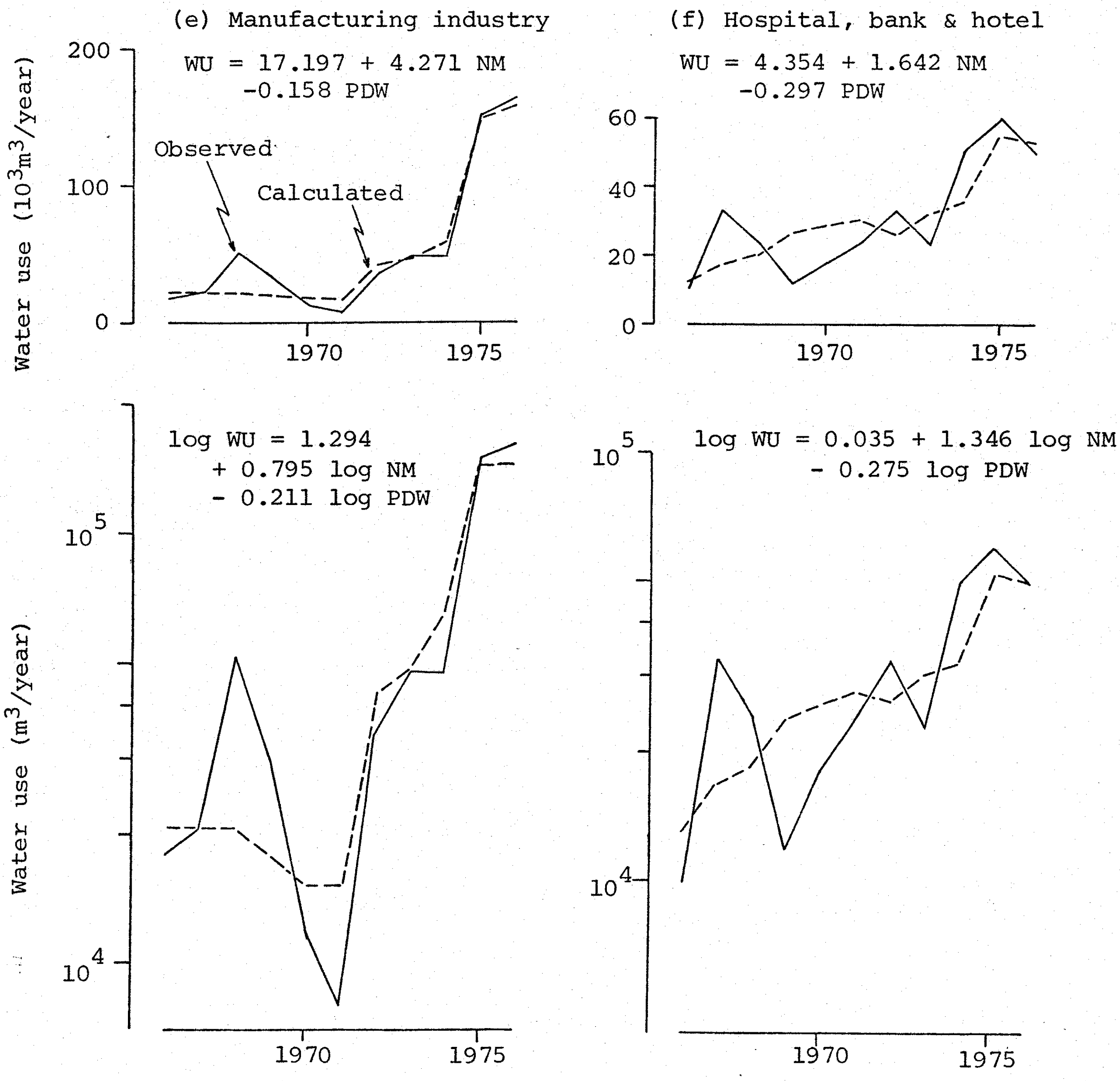


Figure 10 (continued)

(2) and (3)), the retarded growths in observed water use are recognized after 1973, when the severe drought occurred and the oil crisis outbroke. The dummy variables of D are the larger negative values, and this fact suggests that the conservation of industrial water has been made since 1973.

Table 9 contains the elasticities of water demand, defined as the percentage change in quantity consumed associated with 1 % change in a given variable, on the aggregated level. The elasticity of demand is evaluated at the mean values of variable in the linear equation. In the log-linear equation, the constant elasticity of demand is given as the regression coefficient. The elasticities of

Table 9 Elasticities of water demand on the aggregated level

	Elasticity of demand				
	NM	NS	IP	PDC	PDW
Fukuyama municipal					
Total	1.33** to 1.41**	1.17** to 1.29**		-0.25¢ to -0.45*	
Fukuyama industrial					
Rinkai & Hasuike			1.17**		@
Rinkai			0.78** to 1.01**		-0.19
Fuchu municipal					
Total	1.45** to 1.53**			@	
Residential	1.54** to 1.59**			-0.01	
Commercial#	1.36** to 1.55**				@
Civic building & school	2.03** to 2.15**				@
Manufacturing industries	0.80** to 0.82**				-0.14 to -0.21
Hospital, bank & hotel	1.33** to 1.35**				-0.27 to -0.47

Note: NM: the number of metered units NS: the number of use-units
IP: industrial product deflated by the wholesale price index
PDC: the price of water deflated by the consumer price index
PDW: the price of water deflated by the wholesale price index
except for civic building, school, hospital, bank and hotel
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
¢ Significantly different from zero at the 10 percent level.
@ not available

demand with respect to the number of metered units or use-units (NM or NS), or the industrial product (IP) are slightly greater than unity for Fukuyama and Fuchu municipal water uses (total), and nearly unity for Fukuyama industrial water uses. It is remarkable that the elasticity of demand with respect to the number of metered units (NM) is greater than two for civic building and school. The long-term price elasticities of water demand are calculated as -0.25 and -0.45 for total of Fukuyama municipal water use, but no significant price elasticity is derived for other sectors.

3.2 Characteristics of Temporal Variations in Water Use Series

As a water use series seems to have evident seasonal and daily variations, it is important to clarify the seasonal and daily fluctuations of water use series. In this section, the seasonal and daily variations of water use series are investigated by using monthly and daily series data of water use.

3.2.1 Seasonal Variations in Monthly Water Use Series

In general, the behavior of time series data reflects the combined effects of the trend, cyclical, seasonal, and random components of the series.

A time series can be represented by the following multiplicative relationship.

$$X(t) = T(t) \cdot C(t) \cdot S(t) \cdot R(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where X(t) is water use in m^3/sec, T(t) trend component in m^3/sec, C(t) cyclical variation in percent, S(t) seasonal variation in percent, R(t) random variation in percent, and t-th time in month.

A method of link-relatives developed by W. M. Persons (see Takeuchi, K., 1971) is used for the following reason. There is no wide difference in the results obtained by different methods for analyzing time series data. This method does not require tedious calculations, and can separate water use series into seasonal and other components without difficulty. The approach in studying the structure of water use series is based on detecting the seasonal component by calculating the seasonal variation in percent S(t) for each month, and removing the seasonal component from original series X(t). The detailed procedures of the method can be referred to other books on demand forecasting (e.g., Takeuchi, K., 1971).

Three types of water use data are assembled for the present analysis. They are data for irrigation, municipal and industrial water uses. Long-term data for other uses are not available. Four sets of data for irrigation water use (Gokamura, Rokujizo, Imizo and Nanayashiro) are provided by the branch office of the Ministry of Construction in Fukuyama. Two sets of data for municipal water use (Fukuyama and Fuchu) and two sets for industrial water use

(Hasuike and Rinkai) are obtained from the water departments of the respective municipalities.

The seasonal variations in different water uses are shown both in Table 10 and in Figure 11. The location of supply sources is given in Figure 5. Figures 12 to 15 illustrate the monthly water use series X(t) of irrigation, Fukuyama municipal, Fuchu municipal, and industrial water supplies (on the lower part), and their specific series TCR(t) removing the seasonal component from original series X(t) (on the upper part), respectively. The specific series TCR(t) are given as the original series X(t) divided by the seasonal variation S(t).

Monthly series of irrigation water use have evident seasonal fluctuation. Seasonal variations are greater during the irrigation period (June to September) than during the non-irrigation period (October to May). The seasonal variations range from 34 % to 195 % for Gokamura, from 58 % to 180 % for Rokujizo, from 49 % to 212 % for Imizo, and from 67 % to 163 % for Nanayashiro. For the Nanayashiro irrigation water supply, water use series had a depression due to drought in summer of 1973 (Figure 12).

In case of Fukuyama municipal water use, the seasonal variations of each supply source change in the same manner as those of total water use. Total of water use shows the slightly larger value of 116 % in summer and the slightly smaller of 90 % in winter. The increasing trend and the negative jump in summer of 1973 are found in total of water use series (Figure 13). This negative jump also reflects the severe drought in 1973. Though the price of water was risen in June 1965, in May 1973, and in August 1976, no significant reduction of water use was recognized. Both water use series of Kusado and Izuhara sources show the slightly decreasing trends after drought. For Nakatsuhara source, monthly withdrawal is still increasing gradually.

For Fuchu municipal water supply, the seasonal variations range from 91 % to 113 % for total of water use. The seasonal variations differ very markedly among the supply sources. The values of Yodo and Mezaki sources are greater in summer than in winter. On the contrary, those of Deguchi source are smaller in summer than in winter. This is due to the decreasing available water of the Deguchi river in the summer season. It is interesting to note that there is no depression in summer of 1973 and no reduction of withdrawal due to price change (Figure 14).

For industrial water supplies, the seasonal variations in water use series change in the similar pattern as those in total municipal water use. It varies from 92 % to 109 % for Rinkai, and from 89 % to 111 % for Hasuike. Rinkai industrial water supply (on the upper of Figure 15) has a rapidly increasing tendency, and striking negative jump with high randomness due to droughts in 1973 and 1974.

Table 10 Seasonal variations of water use for different purposes

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Records Available
Irrigation	Gokamura	63	53	58	72	108	170	169	195	167	54	34	58	1969. 4 - 1976.12
	Rokujizo	69	77	61	59	80	163	174	180	140	80	58	61	1969. 4 - 1976.12
	Imizo	62	70	68	75	67	150	194	212	140	64	51	49	1969. 5 - 1976.12
	Nanayashiro	67	69	72	74	76	159	144	163	124	83	85	85	1969. 5 - 1976.12
Municipal	Fukuyama	90	92	93	94	98	102	112	116	109	101	97	96	1960. 4 - 1977. 5
	Kusado	85	86	87	91	93	101	117	116	117	106	103	99	1960. 4 - 1977. 5
	Izuhara	91	93	93	95	100	105	112	113	107	99	96	96	1960. 4 - 1977. 5
	Nakatsuhara	89	91	92	94	97	100	113	116	111	104	99	95	1968. 6 - 1977. 5
	Fuchu	91	94	95	97	100	105	113	111	105	101	95	93	1972. 3 - 1977. 2
	Yodo	89	91	90	95	96	105	116	114	112	102	98	92	1972. 3 - 1977. 2
	Hanaka *	94	94	97	98	99	101	109	110	103	101	96	97	1972. 3 - 1977. 2
	Mezaki	75	83	89	90	96	122	132	140	109	99	86	80	1972. 3 - 1977. 2
	Deguchi	116	110	112	103	101	75	81	77	91	108	108	119	1972. 3 - 1977. 2
Indus-trial	Rinkai	92	95	95	97	98	99	106	109	107	104	101	97	1965. 4 - 1977. 6
	Hasuike	89	99	95	93	100	105	111	106	109	103	96	96	1965. 4 - 1977. 5

Note: All values are seasonal variations in per cent of trend component by Persons' method.
* Hanaka: Mezaki and Deguchi sources

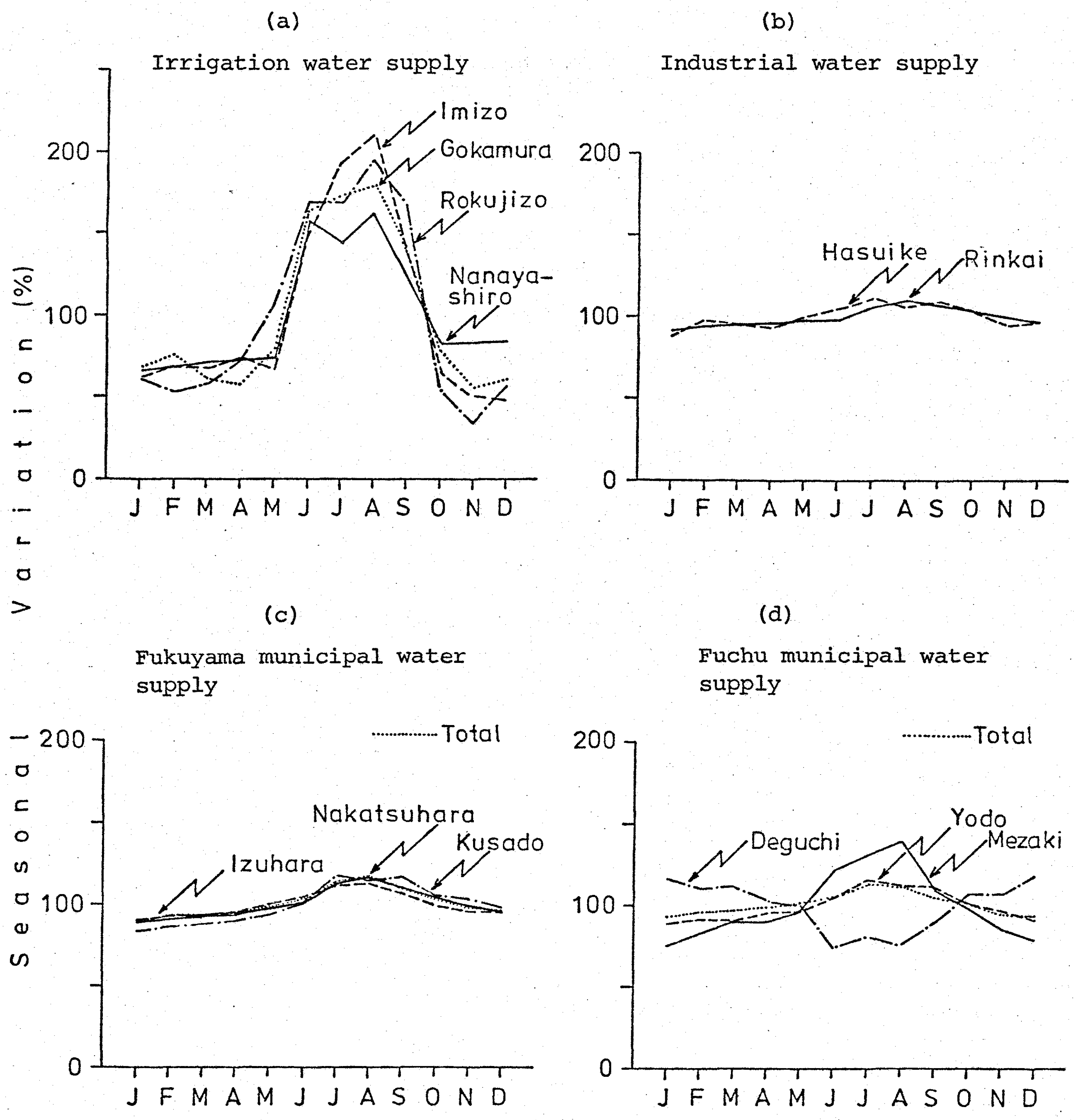
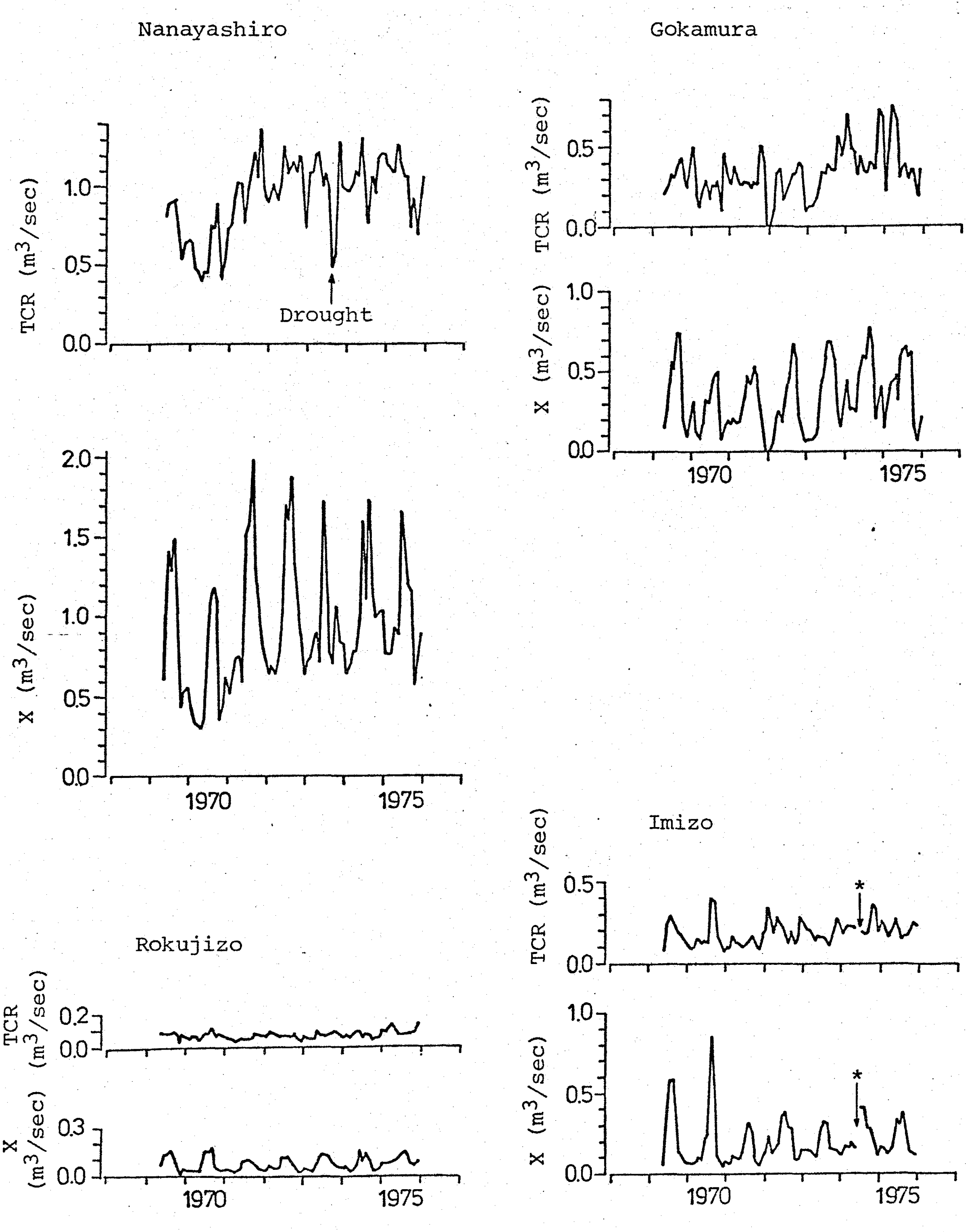


Figure 11 Seasonal variations of water uses for different purposes



X: water use series TCR: trend, cyclical and random components

*: no data

Figure 12 Time series components of irrigation water uses

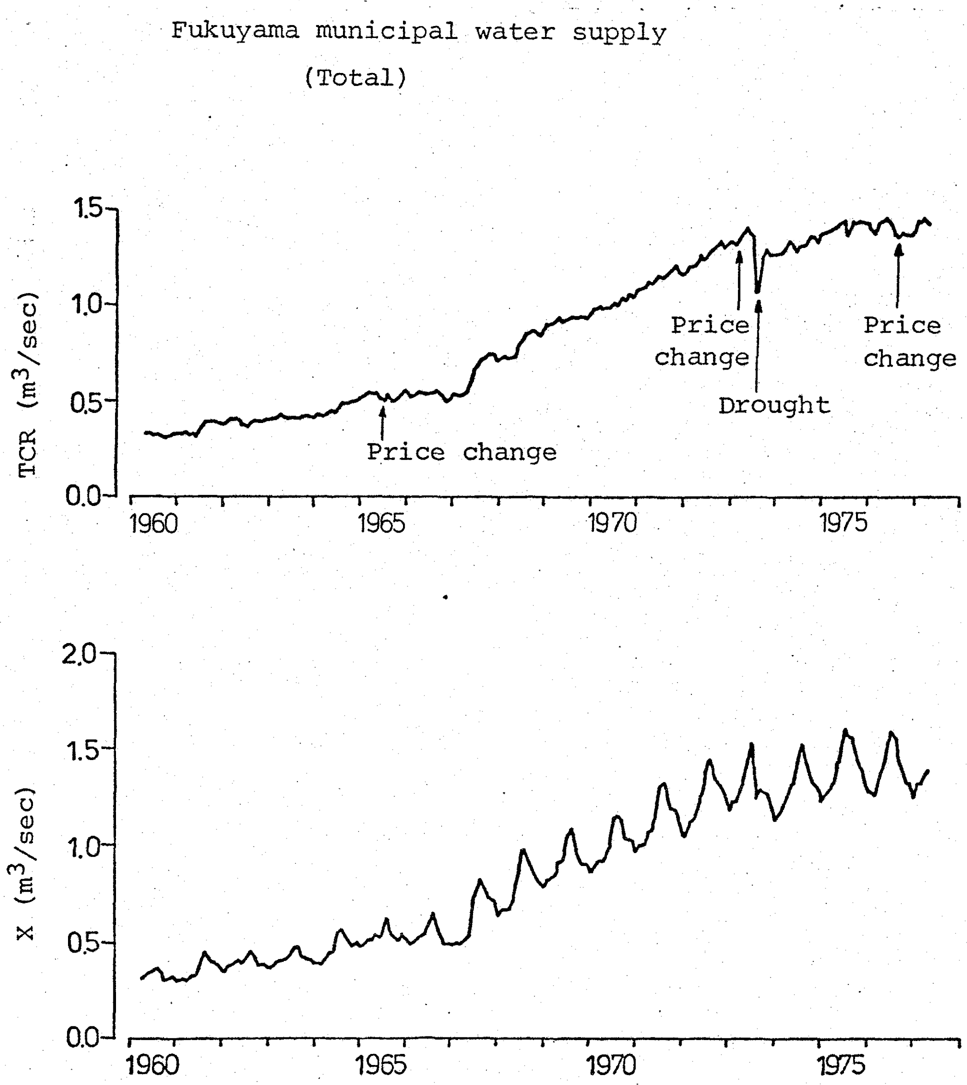


Figure 13 Time series components of Fukuyama municipal water use

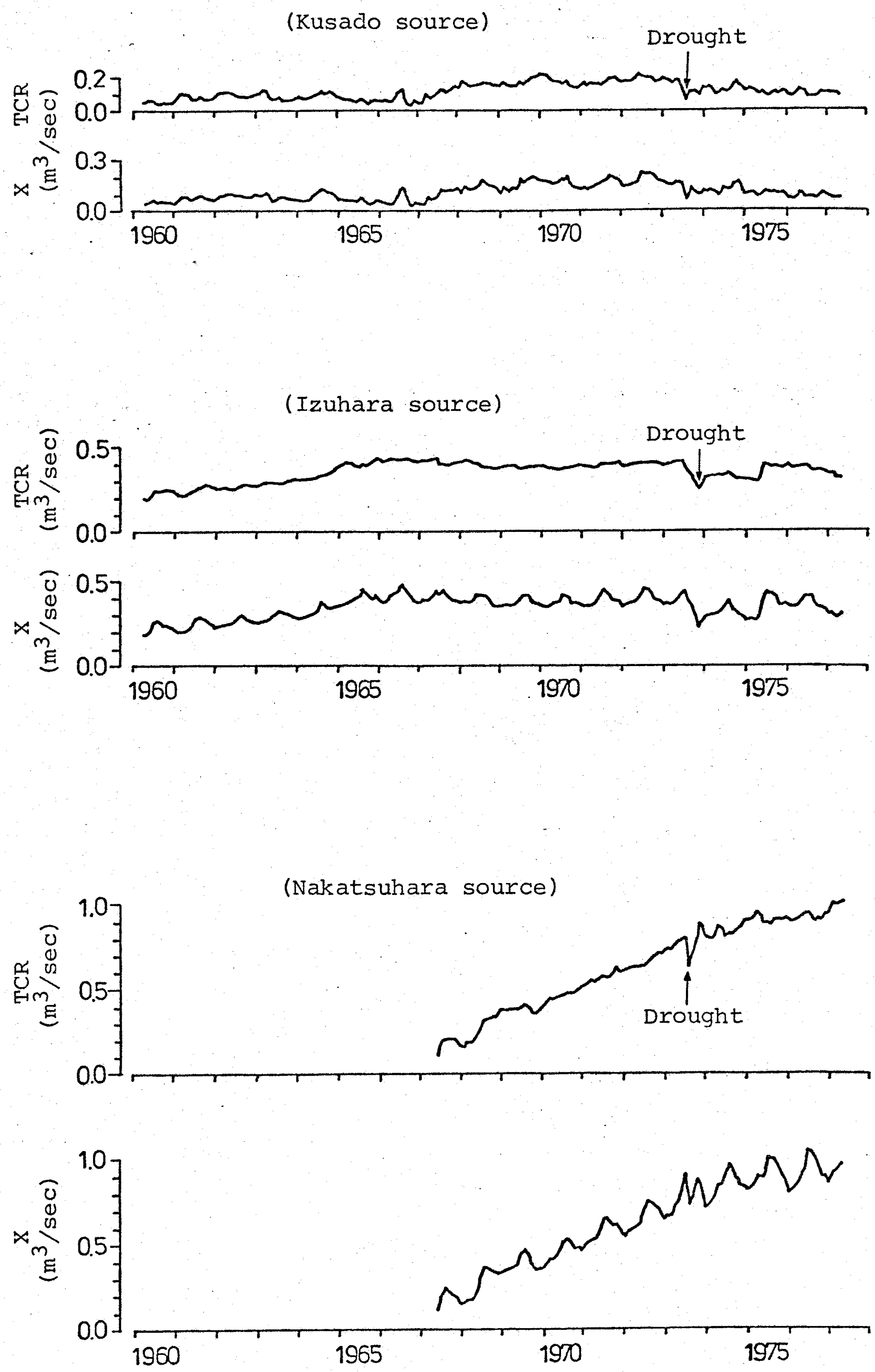


Figure 13 (continued)

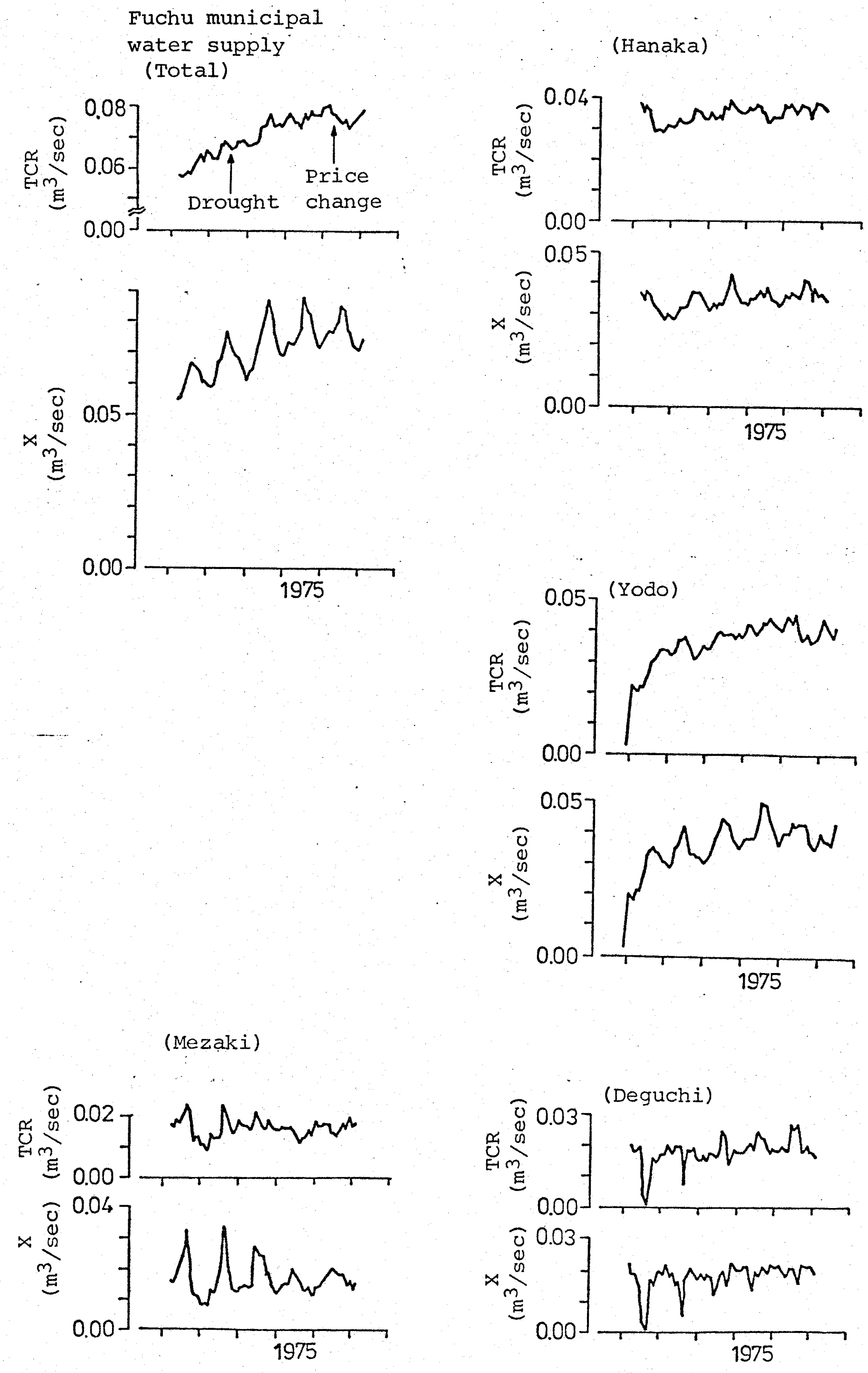
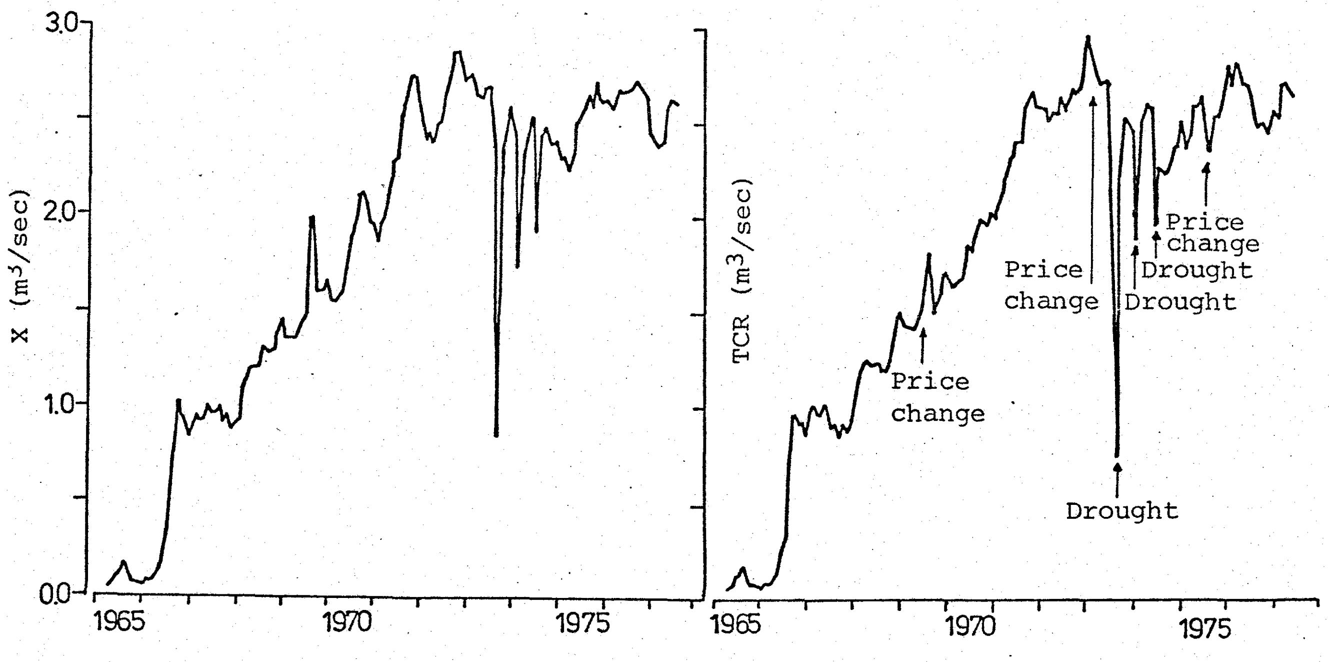


Figure 14 Time series components of Fuchu municipal water use

Rinkai industrial water supply



Hasuike industrial water supply

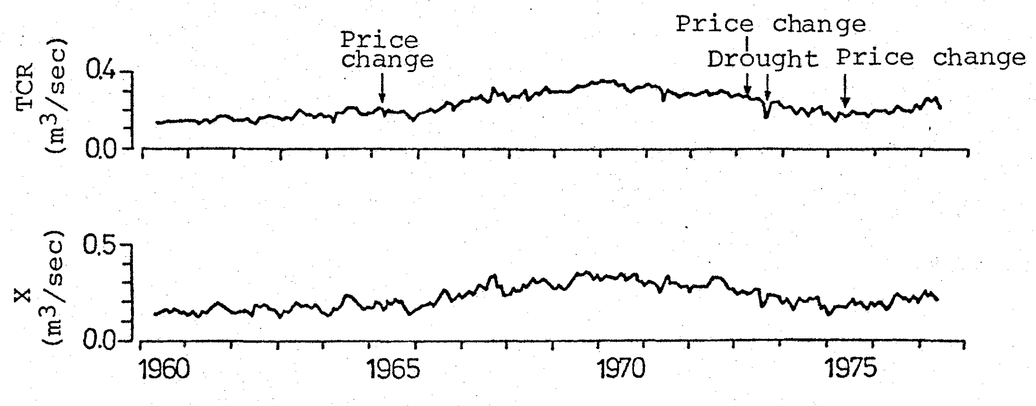


Figure 15 Time series components of industrial water uses

Hasuike industrial water use series (on the lower of Figure 15) has a wavy trend and a small randomness.

3.2.2 Daily Variations in Water Use Series

Figure 16 illustrates the monthly variations of daily withdrawals by sectors for 1972 to 1977. Daily series of water use are not available for Fuchu city. The coefficient of variation of daily withdrawal is given as the standard deviation divided by the mean value for each month. The coefficients of variation range from 0.02 to 1.65 for irrigation, from 0.00 to 0.65 for municipal (Kusado source and Onomichi delivered), from 0.02 to 0.17 for municipal (Nakatsuhara and Izuhara sources), from 0.24 to 0.55 for industrial (Hasuike), and from 0.02 to 0.58 for industrial (Rinkai).

High daily fluctuations of irrigation water uses are partly due to poor management of withdrawal. For Fukuyama municipal water supply, they all have usually small daily fluctuations. In summer of 1973, the peaks in the coefficients of variation are found for Kusado source and the water transferred to Onomichi city, but they are not recognized for Izuhara and Nakatsuhara sources. Water use for Rinkai shows several peaks in August 1973, January 1974, June 1974, August and December 1977. These peaks are mainly due to droughts. For Hasuike industrial water supply, water use has high daily fluctuation. It reflects the decrease in withdrawal every weekend.

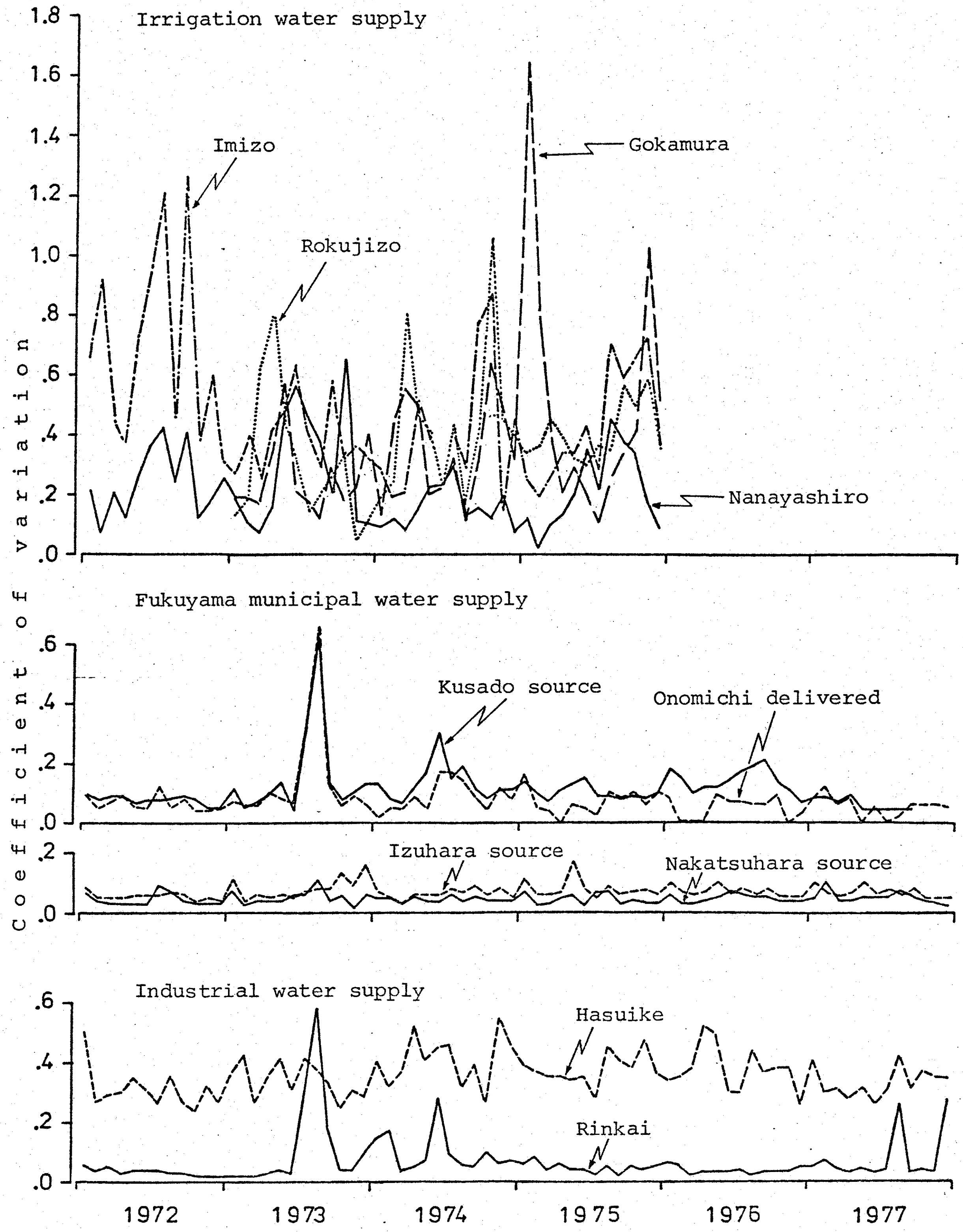


Figure 16 Monthly variations of withdrawals for different types of water use

IV ANALYSIS OF WATER DEMANDS: A SAMPLE SURVEY

In the preceding chapter, the water demand structures are investigated by using the aggregated data on water use. In this chapter, the actual water demand structures for industrial and municipal sectors are clarified in detail on the basis of individual data obtained through the questionnaire survey. The first section treats the water demands in manufacturing industry, commercial and public establishments utilizing a large quantity of water. The second section deals with the water demand in private residence and apartment house.

4.1 Industrial, Commercial and Public Water Demands

4.1.1 The Questionnaire Survey and Sampling Design

The analysis of the present section is based on two investigations. The first is a survey of water use series for 1,135 establishments representing 5.6 % of all 20,427 establishments in Fukuyama and Fuchu cities (Sample I in Table 11). This figure includes 181 manufacturing industries and 954 commercial and public establishments. Fukuyama (1) and (3) include all the establishments supplied with a large quantity of municipal and industrial water. Fukuyama (2) and (4) represent the samples which provide the additional data. The manufacturing industries are classified into several groups on the basis of the Standard Industrial Classification for Japan (JSIC), and

Table 11 Distribution of observations for questionnaire survey for manufacturing industries, commercial and public establishments

		Sample I		Sample II	
Manufacturing industries	Fukuyama(1)	127		59	
	Fukuyama(2)	20	181		69
	Fuchu	34		10	
Commercial and public establishments	Fukuyama(3)	736		191	
	Fukuyama(4)	123	954		208
	Fuchu	95		17	
T o t a l		1,135		277	

Note: Fukuyama(1)&(3): the establishments supplied with large quantity of municipal and industrial water
Fukuyama(2)&(4): the additional observed establishments

Table 12 Groups of industrial, commercial and public establishments

Manufacturing industries	
18,19	Food and kindred products
20	Textile mill products, except apparel and other finished products made from fabrics and similar materials
21	Apparel and other finished products made from fabrics and similar materials
22	Lumber and wood products, except furniture
23	Furniture and fixtures
24	Pulp, paper and paper worked products
25	Publishing, printing and allied industries
26	Chemicals and allied products
27	Petroleum and coal products
28	Rubber products
29	Leather, leather products, and fur skin
30	Ceramic, stone and clay products
31	Iron and steel
32	Non-ferrous metals and products
33	Fabricated metal products
34	Industrial machinery, except electrical machinery
35	Electrical machinery, equipment and supplies
36	Transportation equipment
37	Precision machinery
38	Ordnance and accessaries
39	Miscellaneous manufacturing industries
Commercial and public establishments	
1	Department store and large-scale shop
2	Retail shop
3	Restaurant and tea room
4	Financial and insurance businesses
5	Hotel and motel
6	Government and municipal offices
7	Various kinds of school
8	Hospital
9	Gas station
10	Others
99	Unidentified

the commercial and public establishments are also divided with some consideration of JSIC. Groups of industrial, commercial and public establishments are indicated in Table 12. The water use data are transcribed from meter books of the 1975, 1976 and 1977 fiscal years.

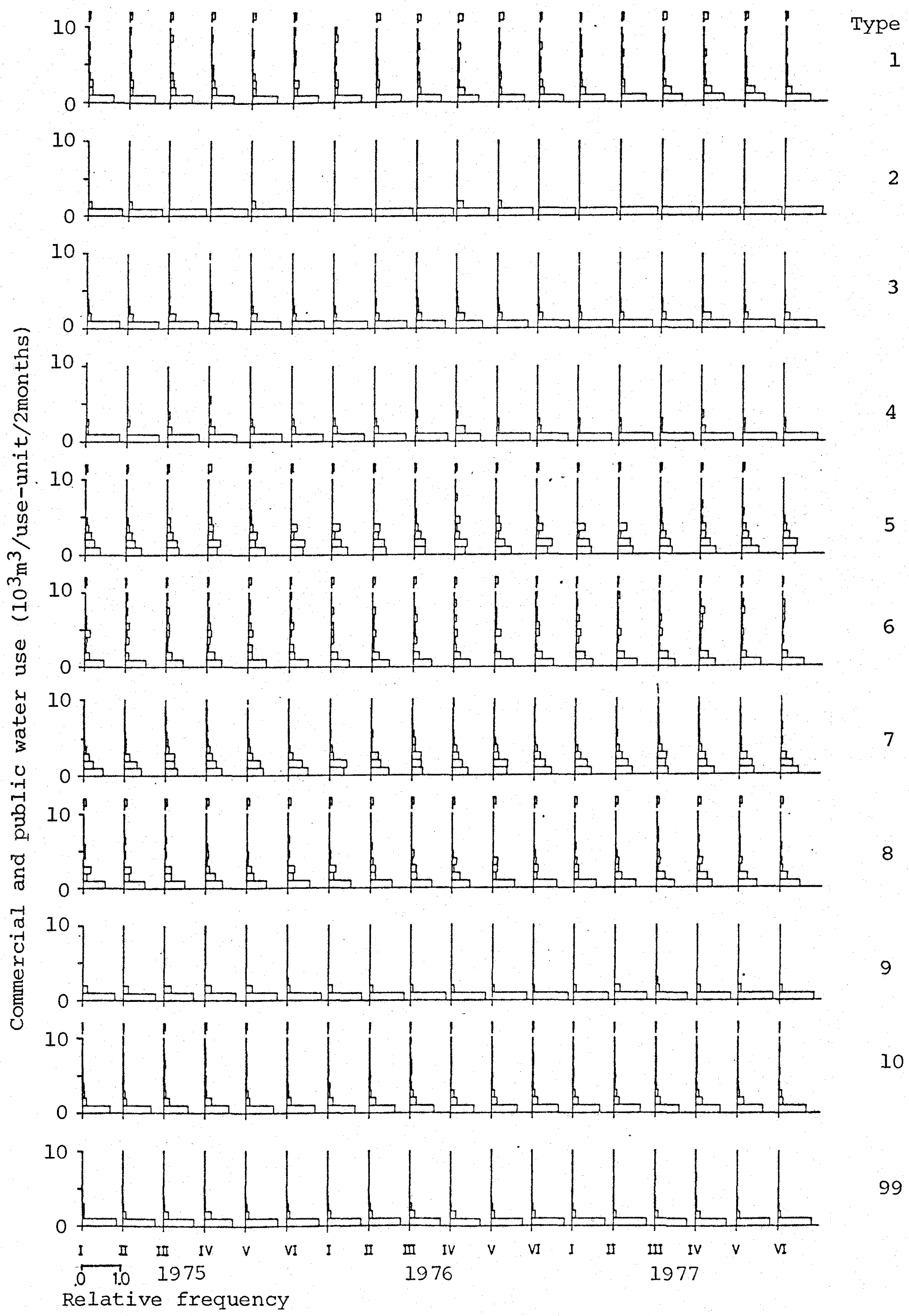
The second is a questionnaire survey to obtain information on the actual condition of water uses for industrial, commercial and public (see APPENDICES A and B). A mail questionnaire survey of 1,135 establishment was conducted from February to March 1978. A number of 277, representing 25 % of all the investigated establishments, was completed. This figure includes 69 manufacturing industries and 208 commercial and public establishments (Sample II in Table 11).

4.1.2 Results of the Survey

(a) General characteristics of industrial, commercial and public water uses

Figure 17 shows the distributions of bimonthly water use series through 1975 to 1977 by groups for Sample I. In this figure, the hights of the various bars indicate the relative frequencies in the various intervals. Table 13 represents the seasonal variations given as bimonthly mean values divided by the annual mean. In general, the seasonal fluctuations are greater in commercial and public water uses than in industrial water use. The following groups have clearly the seasonal variations with the maximum of 132 % to 140 %

Commercial and public water uses for Fukuyama (3)



Note: Type: see Table 12
I: February & March II: April & May III: June & July
IV: August & September V: October & November
VI: December & January

Figure 17 Distributions of commercial, public and industrial establishments for water use

Industrial water use for Fukuyama(1)

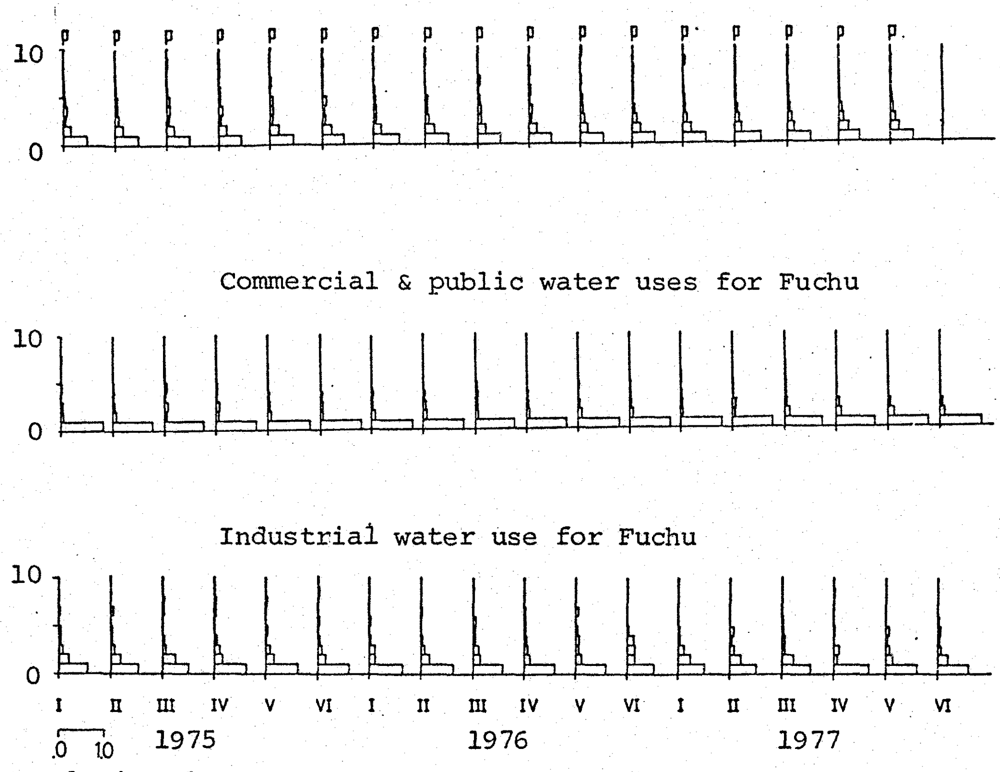


Figure 17 (continued)

Table 13 Seasonal variations of industrial, commercial and public water uses for 1975 to 1977

		Number of observations	I	II	III	IV	V	VI
Industrial water use	Fukuyama(1)	127	104	104	100	100	90	102
	Fukuyama(2)	20	85	97	103	109	102	104
	Fuchu	34	91	100	103	104	100	103
Commercial & public water uses	Fukuyama(3)	736	85	94	113	120	98	89
	1	37	74	90	109	140	102	86
	2	13	82	91	106	132	100	89
	3	117	78	89	111	133	100	88
	4	19	88	87	107	134	94	89
	5	25	90	97	111	111	96	96
	6	36	86	100	106	109	106	93
	7	73	84	90	133	113	97	83
	8	35	92	97	103	113	99	95
	9	50	96	103	107	102	97	95
	10	194	86	94	114	121	97	88
	99	137	87	97	110	118	97	91
	Fukuyama(4)	123	91	96	112	117	96	88
	Fuchu	95	89	102	129	102	87	91

(Column headings I–VI are under the spanning head "Period".)

Note: I: February & March II: April & May III: June & July
IV: August & September V: October & November VI: December & January
1,2,...,99 represent subgroups of establishment: see Table 12
Unit in percent.

in summer and the minimum of 74 % to 88 % in winter. They are Groups 1 (department store and large-scale shop), 2 (retail shop), 3 (restaurant and tea room), 4 (financial and insurance businesses) and 7 (school). These groups largely contribute to the summer increase in municipal water use. The other groups (5, 6, 8 and 9) have the seasonal variations with the maximum of 107 % to 113 % in summer and the minimum of 86 % to 96 % in winter.

The actual conditions of water use in and around the factories are investigated by using the individual data. Table 14 indicates the questionnaire survey results of industrial water use by groups. Answers to questions are plural. Almost all of manufacturing industries are supplied with municipal water and some are supplied with a large amount of industrial water. Ground water is utilized for plant operation in several factories of Fukuyama city, and most of factories utilize ground water in Fuchu city. The 53 factories, representing nearly 80 % of 69 factories, use the recirculated water in and around the factories, and about 40 % for plant operation. Sea water is utilized for plant operation in a factory producing iron and steel. Water conservation by cooling tower for air conditioning is done in around 70 % of all manufacturing industries. It is serious for water quality management that some industries discharge their wastewater directly into natural water system without treating and softening.

Table 14 Results of questionnaire survey for manufacturing industries

	Type of industry	Fukuyama 18,19	Fukuyama 30	Fukuyama 31	Fukuyama 33	Fukuyama 34	Fukuyama Others	Fukuyama Total	Fuchu Total
	Number of observations	21	6	5	4	7	16	59	10
Supply source	Industrial water supply	0	1	2	0	0	7	10	0
	Municipal water supply	20	6	5	4	7	16	58	9
	Self-supplied surface water	0	0	0	0	0	1	1	1
	Self-supplied ground water	6	1	0	0	1	2	10	8
	Recirculated water	17	5	4	4	6	11	47	6
	Self-supplied sea water	0	0	1	0	0	0	1	0
Industrial water use	Industrial boiler feed	11	3	1	1	0	10	26	3
	Incorporate into product	11	5	1	1	0	4	22	2
	Product cooling	7	0	4	1	2	9	23	9
	Washing process	13	6	1	3	1	9	33	8
	Air conditioning	5	0	1	1	1	6	14	1
	Others	8	3	2	0	1	4	18	2
	Recycling for plant operation	4	3	3	3	1	7	21	5
Non-industrial water use	Flush-toilet with public sewer	7	1	0	0	1	6	15	0
	Flush-toilet with septic tank	10	3	4	2	6	7	32	9
	Non-flush toilet	4	2	1	2	0	6	15	5
	Dining room	11	4	3	2	5	10	35	6
	Swimming pool	0	0	0	0	0	1	1	0
	Pond	0	1	2	0	1	2	6	2
	Bathroom	18	4	4	2	5	10	43	7
	Car washer	3	1	2	0	2	2	10	2
	Garden sprinkler	5	3	4	2	3	6	23	4
	Washing machine	11	4	4	0	3	8	30	6
	Others	0	0	0	0	2	1	3	1
	Water conservation by cooling tower for air conditioning	16	3	4	3	6	11	43	6

Table 14 (continued)

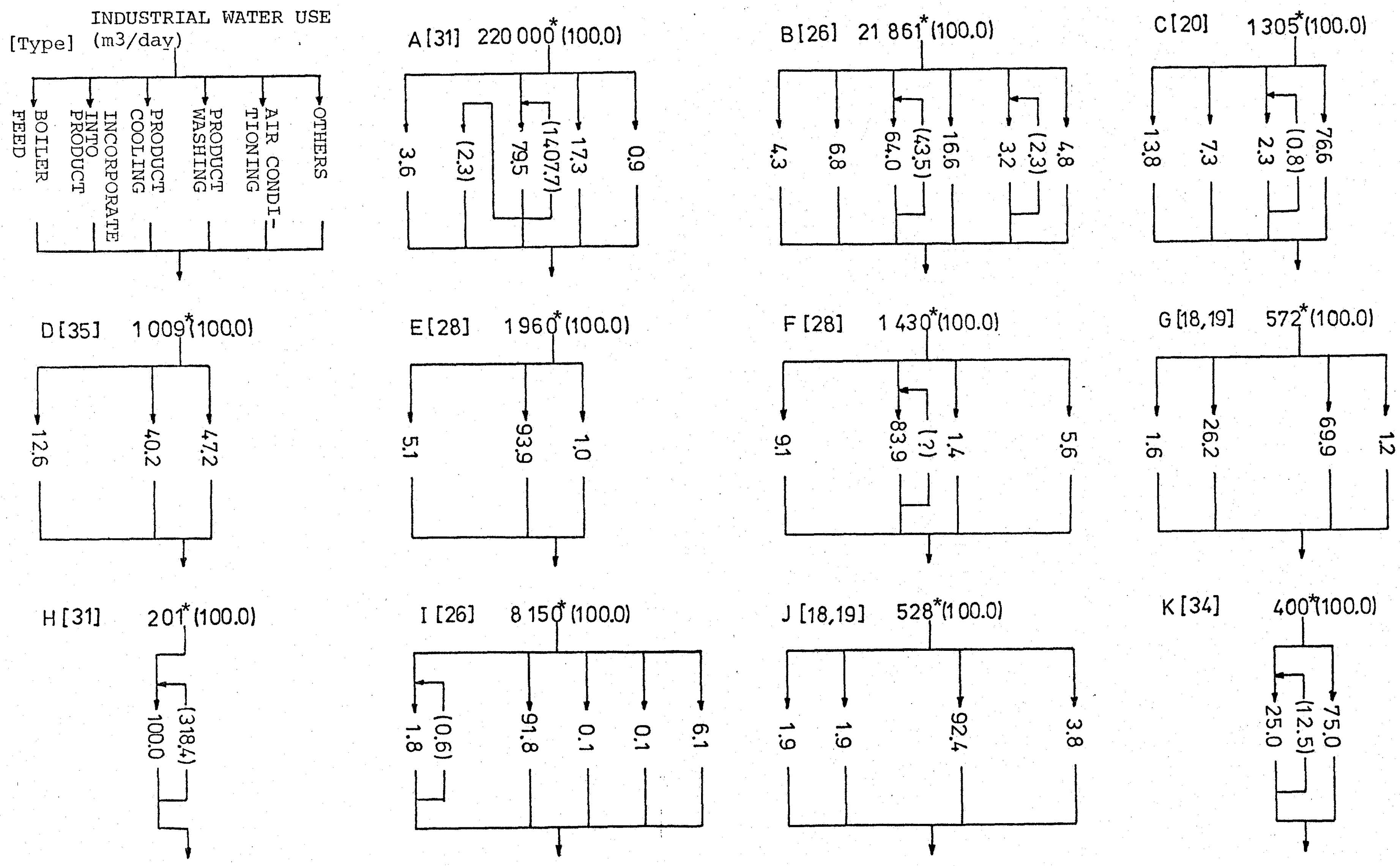
		Type of industry	Fukuyama 18,19	Fukuyama 30	Fukuyama 31	Fukuyama 33	Fukuyama 34	Fukuyama Others	Total	Fuchu Total
Water return	Indus.	Public sewer after treating	3	1	0	0	1	3	8	0
		Surface water after treating	4	3	2	3	1	5	18	4
		Public sewer non-treating	7	1	0	1	1	2	12	1
		Surface water non-treating	1	0	1	1	2	1	6	3
	Non-ind.	Public sewer after treating	5	0	1	0	1	3	10	0
		Surface water after treating	4	1	1	2	1	6	15	4
		Public sewer non-treating	7	2	0	0	2	4	15	1
		Surfacc water non-treating	1	2	3	1	3	10	13	4

Note: 18,19,30,31,33,34 represent types of industry: see Table 12
Figure represents the frequency.
Answers to questions are plural.

Figure 18 shows the water uses for industrial production and processing in 11 factories utilizing more than 200 m^3/day. Values with asterisk represent water use in m3/day, and other values are the percentages of total water use. The water use for product cooling and product washing constitutes 70 % to 100 % of total water use in most of factories. Factory "A" producing iron and steel utilizes water for product cooling repeatedly.

Next, the actual condtions of water use for commercial and public are investigated. The results on commercial and public establishments are listed in Table 15. Answers to questions are also plural. All the commercial and public establishments are supplied with municipal water and two government and municipal offices are supplied with industrial water. About one-tenth of establishments utilizes ground water, and most of them have flush-toilets with public sewer or septic tank. The recirculated water is used for air conditioning in nearly 55 % of 208 establishments. A number of 27 schools (group 7), which is 66 % of all the investigated schools, has swimming pools, and all gas stations (group 9) have car washers.

Table 16 indicates the survey results on water-saving measure, type of flush-toilet and water shortage. Water-saving is done in around 40 % of total commercial and public establishments, and in about 50 % of total manufacturing industries in various ways. Manufacturing



Values with asterisk represent industrial water use in m^3/day.
Other values represent percentages of total water use.

Figure 18 Industrial water use in large-scale factories* for January or February 1978
* water use: more than 200 m^3/day

Table 15 Results of questionnaire survey for commercial and public establishments

	Type of establishment	Fukuyama 1	2	3	4	5	6	7	8	9	10	99	Total	Fuchu Total
	Number of observations	7	6	6	20	10	27	41	15	9	46	4	191	17
supply source	Industrial water supply	0	0	0	0	0	2	0	0	0	0	0	2	0
	Municipal water supply	7	6	6	20	10	27	41	15	9	46	4	191	17
	Self-supplied surface water	0	0	0	0	0	0	0	0	0	2	0	2	0
	Self-supplied ground water	1	2	1	0	2	1	1	1	2	3	0	14	4
	Recirculated water	7	4	4	16	6	19	5	12	2	32	3	110	6
	Self-supplied sea water	0	0	0	0	0	0	0	0	0	0	0	0	0
Water use	Flush-toilet with public sewer	6	2	6	18	7	18	17	8	3	17	2	104	3
	Flush-toilet with septik tank	0	2	0	2	3	8	26	6	6	25	2	80	12
	Non-flush toilet	1	1	0	0	0	1	6	2	0	4	0	15	3
	Air condition	7	4	5	17	7	21	6	12	3	35	2	119	8
	Dining room	6	2	6	11	10	13	30	14	6	27	3	128	10
	Swimming pool	0	0	0	0	0	1	27	1	0	4	1	34	5
	Pond	1	0	0	0	2	5	11	2	0	3	1	25	3
	Bathroom	1	3	4	5	10	18	13	15	0	28	3	100	7
	Car washer	0	0	0	0	1	2	0	0	9	8	0	20	0
	Garden sprinkler	3	2	2	10	7	10	26	7	8	17	1	93	11
	Washing machine	1	3	4	5	8	11	19	4	6	19	3	83	8
	Others	0	0	0	1	0	5	2	2	1	11	0	22	0
	Water conservation by cooling tower for air conditioning	7	4	4	16	6	19	5	12	2	32	3	110	6
Water return	Public sewer after treating	1	3	0	7	3	1	10	3	5	15	1	49	3
	Surface water after treating	0	0	0	0	1	16	14	5	2	14	2	54	4
	Public sewer non-treating	5	2	6	13	6	17	13	7	1	14	0	84	2
	Surface water non-treating	1	0	0	0	0	0	5	0	1	4	1	12	5

Note: 1,2,...,99 represent types of establishment: see Table 12
Figure represents the frequency. Answers to questions are plural.

industries make several improvements in water-using plants and appliances, and commercial and public establishments exercise mainly control of water-using. The water-saving toilet for male sex is commonly used in about 70 % of 225 establishments with flush-toilet, and the water-saving toilet for both sexes in one-half of them. About twenty percent of total establishments are experienced in various kinds of water shortage, but only the few in drought hazards. Restriction on water use is adopted toward a

Table 16 Water-saving and water shortage for questionnaire survey

		Manufacturing industries	Commercial & public establishments
	Total observed establishments	69 (100.0)	208 (100.0)
Efforts to save water	No	32 (46.4)	104 (50.0)
	Yes	36 (52.2)	86 (41.3)
	Public education	3	13
	Water-using control	12	75
	Technological improvement	25	5
	Not clear	1 (1.4)	18 (8.7)
Type of flush-toilet	Number of establishments with flush toilet	56 (100.0)	199 (100.0)
	Toilet for male sex		
	Water-wasting type with high tank	10 (17.9)	60 (30.2)
	Water-saving type with push button or stopcock	43 (76.8)	132 (66.3)
	Not clear	3 (5.4)	7 (3.5)
	Toilet for both sexes		
	Water-wasting type without control of water use rate	22 (39.3)	108 (54.2)
	Water-saving type with control of water use rate	31 (55.4)	92 (46.2)
	Not clear	3 (5.4)	0 (0.0)
Water shortage	No	50 (72.5)	137 (65.9)
	Yes	15 (21.7)	47 (22.6)
	Under droughts	5	18
	In severe winter	4	11
	Others	6	18
	Not clear	4 (5.8)	24 (11.5)

Note: Answers to questions are plural.
The values represent the frequencies.
The values in parentheses represent the relative frequencies in percent.

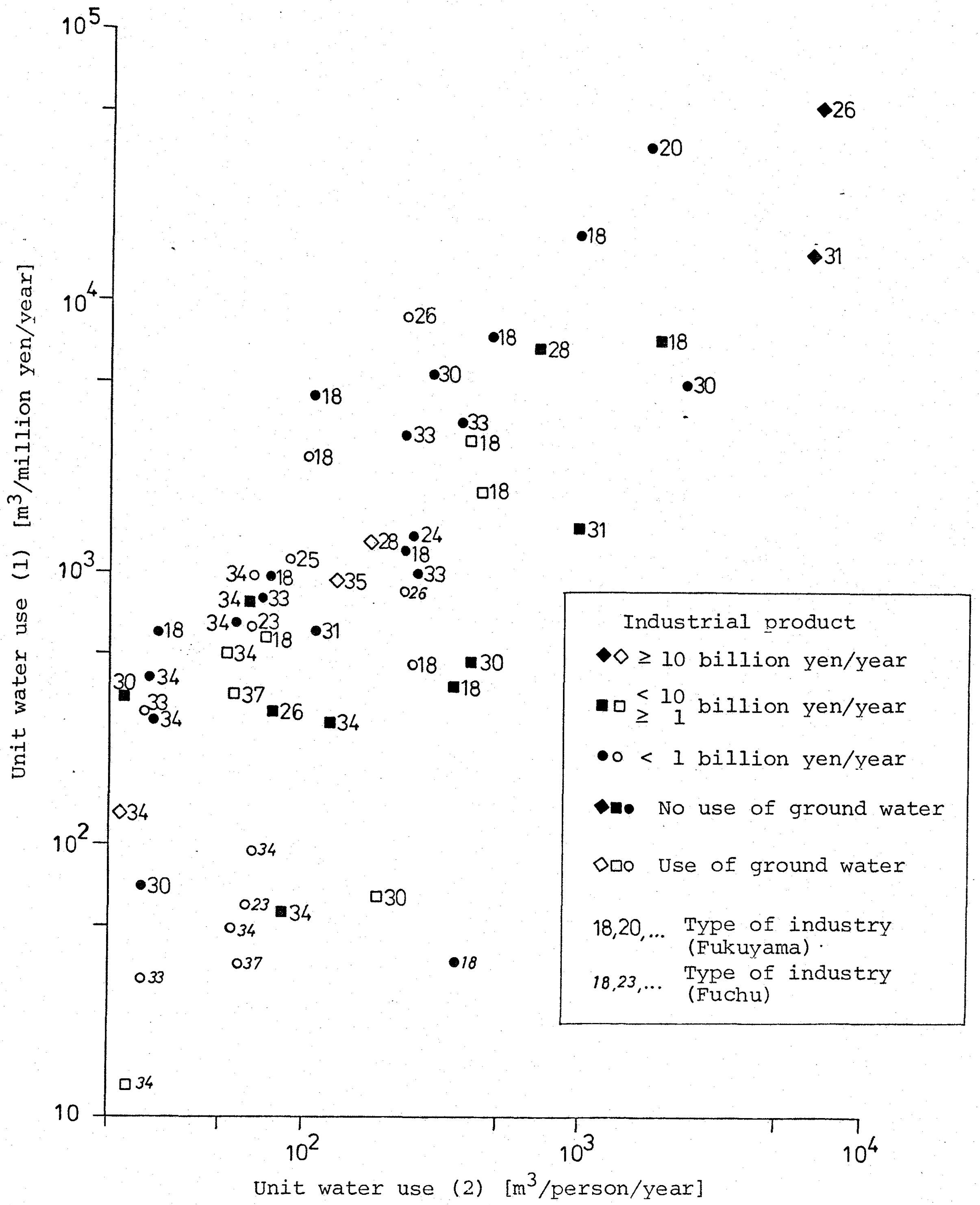
large-scale factory "A", which utilizes about 60 % of total water use in the urban area of Fukuyama city.

(b) Unit water uses for industrial, commercial and public establishments

The factors affecting the unit water use are identified by means of analysis of variance for industrial, commercial and public. Figure 19 illustrates unit water uses (1) and (2) for 55 manufacturing industries, which provide available data for calculating unit water uses. Unit water use (1) [m^3/million yen/year] is the quantity of water use divided by the industrial product, and unit water use (2) [m^3/person/year] is the quantity of water use divided by the number of workers. There are wide differences in both unit water uses. These differences can not be fully explained by variables such as the types of factory, the difference in size of establishment (industrial product), and the presence or absence of ground water use.

Table 17 gives the mean values and the standard deviations of unit water uses (1) and (2) by groups of manufacturing industries, and also indicates the results of analysis of variance. On the basis of analysis of variance, the variation in unit water use (1) can be partially explained by the type of manufacturing industry.

Table 18 lists the unit water uses for various groups of commercial and public establishments, which offer



Note: type of industry: see Table 12

Figure 19 Unit water use for manufacturing industries

Table 17 Unit water uses (1) and (2) by groups of manufacturing industry

(1) Fukuyama manufacturing industries

Group	Unit water use (1) Sample size	Mean	S.D.	Unit water use (2) Sample size	Mean	S.D.
18,19	13	363	470	19	349	435
20	1	3575	@	1	1729	@
21	0	@	@	1	1152	@
23	0	@	@	1	158	@
24	1	133	@	1	242	@
25	1	111	@	1	89	@
26	2	2501	3493	3	2611	3980
27	0	@	@	1	28	@
28	2	389	365	2	439	375
30	6	182	246	6	547	893
31	4	423	710	4	1952	3203
33	4	213	144	4	228	120
34	6	41	26	6	65	37
35	1	94	@	3	121	75

Analysis of variance

	S.S.	DF	M.S.	S.S.	DF	M.S.
Between	20288636	10	2028864	26171268	13	2013175
Within	16871324	30	562378	70045260	39	1796032
Total	37159960	40		96216528	52	
	F = 3.61**			F = 1.12		

(2) Fuchu manufacturing industries

Group	Unit water use (1) Sample size	Mean	S.D.	Unit water use (2) Sample size	Mean	S.D.
18,19	1	37	@	2	243	149
23	1	62	@	1	65	@
26	1	860	@	1	229	@
33	1	31	@	2	119	130
34	3	53	42	3	48	22
37	1	36	@	1	57	@

Analysis of variance

	S.S.	DF	M.S.	S.S.	DF	M.S.
Between	579272	5	115854	64488	5	12898
Within	3470	2	1735	40122	4	10030
Total	582742	7		104610	9	
	F = 66.78*			F = 1.29		

Note: Gruop 18,19,...,37: see Table 12   @: not available
S.S.: sum of squares   DF: the degrees of freedom
M.S.: mean square   F: the variance ratio
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
(1) water use divided by the industrial product ($m^3/10^6$yen/year)
(2) water use divided by the number of persons (m^3/person/year)

available data of water use, the number of workers, and the number of guests and students. Water use per capita (A) is the quantity of water use divided by the number of workers, and water use per capita (B) is the quantity of water use divided by the number of workers, guests and students. There are wide variations in water use per capita for all groups. Even for schools (group 7), the unit water uses (A) and (B) lie unexpectedly in the wide ranges of 11.1 to 59.0 m^3/person/2 months, and of 1.09 to 5.95 m^3/person/ 2 months, respectively. On the basis of analysis of variance, a portion of the variations in both water use per capita is explained by the type of establishment for Fukuyama city. For Fuchu city, on the other hand, it can not be explained by the type of establishment.

To identify the factors causing the difference in unit water use, analysis of variance is done for 39 schools (group 7) of Fukuyama city. Table 19 contains the mean values and the standard deviations of water use per capita (A) and (B) by the type of school (for all the schools), with or without swimming pool (for all the schools), with or without dormitory (for all the schools), with or without swimming pool (for schools with flush-toilet, without dormitory), and by the type of flush-toilet (for 14 elementary schools with flush-toilet and swimming pool, without dormitory). From an analysis of variance, the variations in water use per capita (A) and (B) can be

Table 18 Unit water uses (A) and (B) by groups of commercial and public establishments

(1) Fukuyama commercial and public establishments

Group	Water use per capita (A) Sample size	Mean	S.D.	Water use per capita (B) Sample size	Mean	S.D.
1	7	25.3	8.7	7	0.81	0.34
2	6	42.2	26.9	3	1.34	1.56
3	6	52.2	26.5	4	12.17	11.85
4	17	6.4	5.4	8	4.36	6.67
5	10	109.5	89.7	10	17.02	13.27
6	20	20.2	25.3	14	3.26	3.42
7	40	37.1	12.0	39	2.27	1.04
8	14	35.7	12.3	13	10.32	8.51
9	9	85.0	63.1	8	3.20	2.51

Analysis of variance

	S.S.	DF	M.S.	S.S.	DF	M.S.
Between	96536	8	12067	2537	8	317
Within	132805	120	1107	3431	97	35
Total	229342	128		5968	105	
	F = 10.90**			F = 8.96**		

(2) Fuchu commercial and public establishments

Group	Water use per capita (A) Sample size	Mean	S.D.	Water use per capita (B) Sample size	Mean	S.D.
4	4	17.5	18.9	3	4.31	4.12
6	3	12.0	5.0	2	2.13	2.72
7	2	38.0	18.1	3	2.94	1.04
8	3	29.6	38.0	3	2.70	0.67

Analysis of variance

	S.S.	DF	M.S.	S.S.	DF	M.S.
Between	1064	3	355	6.82	3	2.27
Within	4332	8	542	44.34	7	6.33
Total	5396	11		51.16	10	
	F = 0.66			F = 0.36		

Note: Group 1,2,...,9: see Table 12
S.S.: sum of squares DF: the degrees of freedom
M.S.: mean square F: the variance ratio
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
(A): water use divided by the number of workers (m^3/person/2 months)
(B): water use divided by the number of workers, guests and students (m^3/person/2 months)

Table 19 Unit water uses (A) and (B) by subgroups of school

(1) Types of school

Type	Water use per capita (A) Sample size	Mean	S.D.	Water use per capita (B) Sample size	Mean	S.D.
7-1	20	42.7	9.8	19	2.18	0.60
7-2	7	31.6	7.6	7	1.61	0.55
7-3	4	36.3	19.9	4	2.78	2.19
7-4	2	30.5	6.9	2	4.78	0.15
7-5	1	23.4	@	1	1.64	@
7-6	6	31.3	12.3	6	2.27	0.48

Analysis of variance

	S.S.	DF	M.S.	S.S.	DF	M.S.
Between	1324	5	265	17.2	5	3.45
Within	4162	34	122	23.9	33	0.73
Total	5485	39		41.2	38	
	F = 2.16¢			F = 4.75**		

Note: Type 7-1: Elementary school; 7-2: Junior high school; 7-3: High school; 7-4: College & junior college; 7-5: Professional school; 7-6: Kindergarten

(2) With or without swimming pool

	Water use per capita (A) Sample size	Mean	S.D.	Water use per capita (B) Sample size	Mean	S.D.
With	28	39.3	11.3	27	2.28	0.74
Without	12	32.9	12.6	12	2.25	1.56

Analysis of variance

	S.S.	DF	M.S.	S.S.	DF	M.S.
Between	344	1	344	0.01	1	0.01
Within	5141	38	135	41.17	37	1.11
Total	5485	39		41.17	38	
	F = 2.55			F = 0.01		

(3) With or without dormitory

	Water use per capita (A) Sample size	Mean	S.D.	Water use per capita (B) Sample size	Mean	S.D.
With	2	47.2	16.8	2	5.42	0.76
Without	38	36.8	11.6	37	2.10	0.74

Analysis of variance

	S.S.	DF	M.S.	S.S.	DF	M.S.
Between	203	1	203	20.9	1	20.9
Within	5283	38	139	20.3	37	0.5
Total	5485	39		41.2	38	
	F = 1.46			F = 37.97**		

Table 19 (continued)

(4) With or without swimming pool (for schools with flush-toilet, without dormitory)

	Water use per capita (A)			Water use per capita (B)		
	Sample size	Mean	S.D.	Sample size	Mean	S.D.
With	27	39.5	11.3	26	2.23	0.71
Without	10	30.0	10.4	10	1.62	0.51

Analysis of variance

	S.S.	DF	M.S.	S.S.	DF	M.S.
Between	664	1	664	2.68	1	2.68
Within	4312	35	123	14.79	34	0.44
Total	4976	36		17.47	35	
	F = 5.39*			F = 6.15*		

(5) Type of flush-toilet (for elementary schools with flush-toilet, with swimming pool, without dormitory)

	Water use per capita (A)			Water use per capita (B)		
	Sample size	Mean	S.D.	Sample size	Mean	S.D.
Water-saving type	9	42.2	9.6	9	2.03	0.50
Water-wasting type	5	48.5	6.3	5	2.50	0.30

Analysis of variance

	S.S.	DF	M.S.	S.S.	DF	M.S.
Between	126	1	126	0.73	1	0.73
Within	900	12	75	2.36	12	0.20
Total	1026	13		3.09	13	
	F = 1.68			F = 3.71¢		

Note: S.S.: sum of squares DF: the degrees of freedom
M.S.: mean square F: the variance ratio
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
¢ Significantly different from zero at the 10 percent level.
@ not available
(A): water use divided by the number of workers (m^3/person/2 months)
(B): water use divided by the number of workers, guests and students (m^3/person/2 months)

partly explained by the type of school, and the presence or absence of dormitory. For 36 or 37 schools with flush-toilet, without dormitory, the presence or absence of swimming pool significantly affects the unit water use.

Table 20 contains the results of the regression of water use per capita (B) on the two explanatory variables for 36 or 35 schools with flush-toilet, without dormitory. It is interesting to note that the regression coefficient of a_1, representing the size of school, has a negative value. It indicates that the water use per capita decreases with the increasing number of teachers and students.

Furthermore, the 14 elementary schools (with flush-toilet, without dormitory) are divided into two groups to evaluate the effect of different types of flush-toilet on water use. The water use per capita (B) accounts for average of 2.03 m^3/person/2 months for elementary schools with water-saving toilet, and average of 2.50 m^3/person/

Table 20 Water demand equations for school

Schools with flush-toilet, without dormitory

$Y = a_0 + a_1 X_1 + a_2 X_2$ $\log Y = b_0 + b_1 \log X_1 + b_2 X_2$

Y: water use per capita (B) in m^3/person/2 months

X_1: the number of teachers and students

X_2: dummy variable (1= with swimming pool, 0= without swimming pool)

	a_0	a_1	a_2	R	F	d.f.	b_0	b_1	b_2	R	F
(1)	1.914	-0.0005**	0.719**	.544	6.92**	33	0.636	-0.167**	0.165**	.601	9.34**
		(2.58)	(3.11)					(2.97)	(3.68)		
(2)	1.860	-0.0004**	0.608**	.578	8.02**	32	0.602	-0.154**	0.151**	.612	9.59**
		(2.73)	(3.41)					(3.06)	(3.72)		

Note: (1) 36 schools (including college) (2) 35 schools (except for college)
a_i, b_i: the regression coefficient
the value in parenthesis: t-value
R: the multiple correlation coefficient
F: the variance ratio d.f.: the degrees of freedom
** Significantly different from zero at the 1 percent level.

2 months for elementary schools with water-wasting toilet (Table 19(5)). There is a difference in water use per capita (B) by the type of flush-toilet.

(c) Price sensitivities of industrial, commercial and public water demands

In general, consumer response to a given variable is conveniently measured by the concept of elasticity of demand. The price elasticity of demand (E_p) is the relative change in quantity with a change in price, and it is given as follows:

$$E_p = (\partial Wu/Wu)/(\partial Pr/Pr) \quad \text{.........................(7)}$$

where Wu is the water use in establishment and Pr the price of water. Goods whose elasticity is greater than unity are said to be in elastic demand, and those whose elasticity is less than unity in inelastic demand.

To estimate the price elasticity of demand for water, the water demand functions are determined for groups of establishment by using cross-sectional data on individuals. The demand function includes variables such as the industrial products, the number of workers, the number of workers, students and guests, and the price of water. Though several types of demand models are tested by using linear and log-linear equations, all of the regression coefficients of price are not significantly from zero at the 10 % level.

To evaluate the effect of price change on water use, the annual water uses before and after changing rate schedule are compared by the types of establishment. The municipal water rates were changed in August 1976 for Fukuyama, and in April 1976 for Fuchu. The old and the new water rate schedules and the percentage changes are indicated in Table 21. Table 22 contains a comparison of mean water uses before and after changing municipal water rate for establishment. On the aggregated level, the reduction of mean water use is found for all sectors. The reduction of water use accounts for 96.2 m^3/use-unit/year in commercial and public establishments (Fukuyama (3)), for 220.2 m^3/use-unit/year in commercial and public (Fuchu), and for 3.8 m^3/use-unit/year in manufacturing industries (Fuchu). For commercial and public establishments in Fukuyama (3), however, the decreasing water use is recognized for the types of establishment with the exception of type 1 (department store and large-scale shop), type 2 (retail shop), type 5 (hotel and motel), and type 7 (school). The unexpected positive sign of change in water use indicates that water demand depends not so much upon the price of water as upon the other variables for the above groups of establishment.

Table 21 The old and the new water rate schedules

		Basic fee in yen	Block rate in yen/m^3 0-7	8-10	11-15	16-20	21- (m^3)
Fukuyama	Old	290	0	0	40	45	55
	New	400	0	0	60	70	90
		38*	-	-	50*	56*	64*
Fuchu	Old	380 (750)	0	60	60	60	60
	New	500 (1000)	0	80	80	80	80
		32* (33*)	-	33*	33*	33*	33*

Note: Values in parentheses represent the basic fee for industrial, commercial and public establishments.
* Percentage change in price of water.
Water rates were changed in August 1976 for Fukuyama, and in April 1976 for Fuchu.

Table 22 Mean water uses before and after changing water rate schedule for manufacturing, commercial and public establishments

	Mean water use per use-unit (m^3/use-unit/year) Before changing rate schedule	After changing rate schedule	Difference
Commercial and public establishments			
Fukuyama (3)	8 080.5	7 984.3	-96.2
1	13 828.9	14 436.1	+607.2
2	2 540.9	2 601.4	+60.5
3	4 344.9	4 232.7	-112.2
4	4 502.1	4 136.1	-366.0
5	15 607.4	15 627.5	+19.9
6	19 383.8	18 695.0	-688.8
7	9 049.3	9 512.4	+463.1
8	13 815.6	13 775.6	-40.0
9	3 858.9	3 667.9	-191.0
10	9 506.4	9 185.2	-321.2
99	3 936.4	3 862.1	-74.3
Fuchu	3 515.8	3 295.6	-220.2
Manufacturing industries			
Fuchu	7 277.9	7 274.1	-3.8

Note: 1,2,...,99 represent the type of commercial and public establishments: see Table 12

4.2 Residential Water Demand

4.2.1 Models for Analysis of Residential Water Demand

The amount of water use by dwelling unit in a given time period was a function of the number of water-using appliances in and around the house and the probability of turning on those appliances (Grima, A. P., 1972). This functional relationship can be shown as follows:

$$Rwu = \sum^{m} d_i = \sum^{m} n_i \, w_i \, p_i \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where Rwu is the residential water use in household, d_i the amount of water used by appliance i, n_i the number of appliances of type i, w_i the rate of water used by appliance i, p_i the probability of turning on the appliance i, and m the number of appliance types.

It is very difficult to have complete information on the values of n_i, w_i, p_i and m for a large number of households. For instance, the measurement of the rate and quantity of water used by appliances can be obtained by using flow meters, but this method can not be used because of the laborious and expensive investigation.

In this section, the amount of information required to estimate the residential water demand equation is replaced by a small number of relevant explanatory variables. The factors affecting the residential water use are classified into four groups: physical (temperature, precipitation, evapotranspiration,...), socio-economic (the number of persons in household, family income, dwelling type, price of water,...), technological (water-using appliances, water pressure,...), and behavioral (probability of turning on the appliances, whether or not saving water,...).

The problem in analyzing water demands is to identify the relevant variables. Because there is no significant spatial difference in climatic condition through this study area, the physical factors can be neglected. In the earlier study, Shimmi, O. (1977) derived the residential water demand functions for households supplied only with municipal water. A portion of the variation in water use was explained by the number of persons in household, and the dummy variables representing the presence or absence of bath, flush-toilet and water-saving.

In the present study, the following three types of residential water demand models with dummy variables are tested using linear equations.

Model A is hypothesized that:

$$Rwu = f(Np, Np2, Gw, Nrwu, Bt, Wash, Tl, Dw, Othu, Inc) \quad .....(9)$$

and specifically that:

$$Rwu = a_0 + a_1Np + a_2Np2 + a_3Gw + a_4Nrwu + a_5Bt + a_6Wash + a_7Tl + a_8Dw + a_9Othu + a_{10}Inc \quad ....(10)$$

where Rwu is the residential water use in m^3/household/year, Np the number of persons in household, Np2 the number of babies (under two years old) in household, Inc the income in million yen/household/year, and the others dummy variables.

That is,

Gw = 1 if the household uses ground water,
= 0 otherwise;

Nrwu = 1 if water is used for non-residential purposes,
= 0 otherwise;

Bt = 1 if the household has a bath,
= 0 otherwise;

Wash = 1 if the household has a washing machine,
= 0 otherwise;

Tl = 1 if the household has a flush-toilet,
= 0 otherwise;

Dw = 1 if the household is a single unit,
= 0 otherwise,

Othu = 1 if water is used for other residential purposes (such as pond, dish washer,...),
= 0 otherwise,

and a_i (i=0,1,...,10) represent regression coefficients. Regression coefficients of a_1, a_2, a_4, a_5, a_6, a_7 and a_9 are expected to be positive, and a_3 is expected to be negative.

It is so difficult to obtain the income data that the observations supplied for analysis are limited in number, and they include inevitably some of households using a large amount of water for non-residential purposes.

Next, the households which use their water only for residential purposes (Nrwu=0, Bt=1) are analyzed.

Model B is hypothesized that:

$$Rwu = f(Np, Gw, Sw1, Sw2, T1, Dw, Othu) \quad \text{................(11)}$$

and specifically that:

$$Rwu = b_0 + b_1Np + b_2Gw + b_3Sw1 + b_4Sw2 + b_5T1 + b_6Dw + b_7Othu \quad \text{...........(12)}$$

where Sw1 and Sw2 are the dummy variables on water-saving. That is,

Sw1 = 1 if water for bathing is used repeatedly,
= 0 otherwise;

Sw2 = if the water for bathing is used for washing,
= 0 otherwise,

and other variables are defined as before. Regression coefficients of b_1, b_5, b_6 and b_7 are expected to be positive, and b_2, b_3 and b_4 to be negative.

Moreover, the households without babies utilizing water only for residential purposes (Np2=0, Nrwu=0, Bt=1) are analyzed.

Model C is hypothesized that:

$$Rwu = f(Np, Gw, T1, Othu, Inc, Pr) \quad \text{....................(13)}$$

and specifically that:

$$Rwu = c_0 + c_1Np + c_2Gw + c_3T1 + c_4Othu + c_5Inc + c_6Pr \quad \text{.............(14)}$$

where Pr is average price of water, which is given as the total fee of water divided by the amount of water used, and other variables are defined before. All of the regression coefficients with the exception of c_2 and c_6 are expected to be positive.

The above demand equations are tested by all-possible-regression method. All-possible-regression involves calculating regression equations having every possible combination of the explanatory variables.

The elasticity of demand is the relative change in quantity with a change in a given variable. The elasticities of price (E_p), of income (E_i), and of household-size (E_{Np}) for residential water demand are given as follows:

$$E_p = (\partial Rwu/Rwu)/(\partial Pr/Pr) \quad \text{.....................(15)}$$

$$E_i = (\partial Rwu/Rwu)/(\partial Inc/Inc) \quad \text{....................(16)}$$

$$E_{Np} = (\partial Rwu/Rwu)/(\partial Np/Np) \quad \text{.....................(17)}$$

where Rwu is the residential water use in household, Pr the price of water, Inc the family income, and Np the number of persons in household.

4.2.2 The Questionnaire Survey and Sampling Design

The questionnaire was designed to obtain information on the factors which have any effect on residential water use (see APPENDIX C). A questionnaire survey of 3,200 households was done in the following way (Table 23 and Figure 20).

Ten elementary school districts were chosen in the lower and middle parts of the basin (A, B, C, D and E in the lower basin; F, G, H, I and J in the middle basin). Districts A and B lie in the central part, C and D in the

Table 23 Distribution of observations for questionnaire survey for residential water use

District	Sample I	Sample II	Sample III	Sample IV	Sample V
A	293	187	71	159	63
B	322	176	75	126	60
C	191	152	75	143	73
D	305	260	143	255	132
E	321	235	83	200	71
F	218	146	52	131	42
G	313	169	76	147	66
H	226	52	30	49	28
I	199	35	17	30	15
J	235	78	7	63	6
K	290	73	57	67	51
L	196	129	91	119	66
M	91	24	18	23	-
Total	3,200	1,716	795	1,512	673
N	-	-	538	-	465
O	-	-	257	-	-
P	-	-	-	97	-
Q	-	-	-	-	208

Note: A,B,C,D,E,F,G,H,I,J: elementary school districts
K: data obtained through mail questionnaire survey
L: staffs of Fukuyama waterworks in the lower basin
M: staffs of Fukuyama waterworks in the middle basin
N: A,B,C,D,E & L   O: F,G,H,I,J,K & M
P: I & K   Q: F,G,H,I,J & K

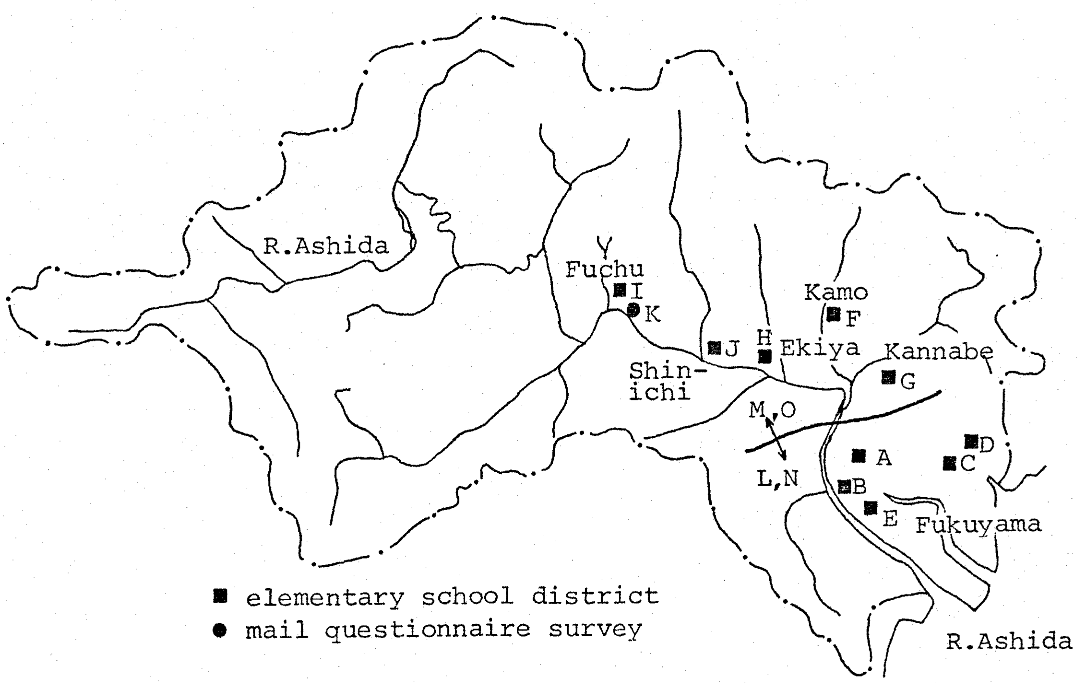


Figure 20 Location map of sampling districts for questionnaire survey of residential water use

new residential area, and E in the suburban area of Fukuyama city. District I lies in the central part of Fuchu city. Other districts are in the rural areas (F in Kamo, G in Kannabe, H in Ekiya, J in Shin-ichi). A questionnaire survey of 2,623 households was conducted in the above ten districts from August to October 1977. This survey has the advantage of providing a large number of sets of data, but the disadvantage of having a bias in sampling data on the age of the head and the type of occupation. To make up for the above weak point of the survey, two questionnaires were distributed to each pupil. One is for his own family and another for his neighbor without pupils.

As the questionnaire was formulated to obtain the answer's name and income, a large number of persons refused to answer questions, especially in Fuchu city. Therefore, the additional questionnaire survey was conducted. The additional data were obtained from 290 households (district K in the new residential area of Fuchu city) through mail questionnaire survey, and from 287 staffs of Fukuyama waterworks (L in the lower basin, M in the middle basin).

The water use series of individual households were transcribed from meter books of respective municipalities for the 1975, 1976 and 1977 fiscal years. The water meters were read every one to two months.

Sample I is all of 3,200 households for questionnaire survey and the number of households for district ranges from 91 to 322. The number of available data differs markedly among different questions. Sample II includes 1,716 households which are supplied with municipal water and offer available data on water use series, representing 54 % of all the observations. Sample III includes 795 households for analysis by model A, Sample IV is 1,592 households for analysis by model B, and Sample V is 673 households for analysis by model C. Samples III, IV and V represent 25 %, 50 %, and 21 % of all the 3,200 observations, respectively.

4.2.3 Results of the Survey

(a) General characteristics of residential water use

Variables for residential water use are presented in Table 24. Table 25 gives the mean values of variables and Figure 21 represents the results of qualitative variables for Sample I.

The mean number of persons in household (Np) ranges from 3.93 in the district K to 4.92 in the district F. The larger values are partially due to lacking in small sized households.

The mean values of income (Inc) are in the ranges of 3.3 to 4.4 million yen/household/year.

The mean values of the number of babies (under two years old; Np2) are larger in the districts of L and M than in other districts (0.25 in L, 0.28 in M; 0.01 to 0.12 in

Table 24 Variables of residential water use for questionnaire survey

No.	Number of observations
Np	Number of persons in household
Inc	Income in household (million yen/household/year)
Rwu	Residential water demand (m^3/household/year)
Rwua	Average residential water demand (m^3/household/2months)
Rwus	Summer residential water demand (m^3/household/2months)
Rwuw	Winter residential water demand (m^3/household/2months)
Np2	Number of persons under 2 years old in household
Pws	A dummy variable taking the value 1 if the household is supplied with public water and being zero otherwise
Gw	A dummy variable taking the value 1 if the household uses ground water and being zero otherwise
Nrwu	A dummy variable taking the value 1 if water is used for non-residential purposes and being zero otherwise
Bt	A dummy variable taking the value 1 if the household has a bath and being zero otherwise
Sw1	A dummy variable taking the value 1 if water for bathing is used repeatedly and being zero otherwise
Sw2	A dummy variable taking the value 1 if the used water for bathing is reused for washing and being zero otherwise
Wash	A dummy variable taking the value 1 if the household has a washing machine and being zero otherwise
Tl	A dummy variable taking the value 1 if the household has a flush-toilet and being zero otherwise
Dw	A dummy variable taking the value 1 if the house is single unit and being zero otherwise
Spr	A dummy variable taking the value 1 if water is used for garden sprinkling and being zero otherwise
Carw	A dummy variable taking the value 1 if water is used for car washing and being zero otherwise
Othu	A dummy variable taking the value 1 if water is used for other residential purposes and being zero otherwise
Pw	A dummy variable taking the value 1 if public water rate is felt to be expensive and being zero otherwise
s/a	Rwus/Rwua
w/a	Rwuw/Rwua
Rwc	Residential water demand per capita (m^3/person/year)

others). This difference can be explained by the difference in age of the head in household.

Most of households are supplied with municipal water (Pws) as main source, with the exception of district J. Ground water (Gw) is more widely used in the rural districts (such as F, G, H, J and M) than in the urban districts (such as A, B, C, D, E, I, K and L). Especially in the district J, ground water (Gw) is utilized as main source in about a half of households.

In the urban districts of A, B and I, water is used for non-residential purposes (Nrwu), that is, for commercial activities.

Table 25 Mean values of variables for Sample I

District	A	B	C	D	E	F	G	H	I	J	K	L	M
No.	293	322	191	305	321	218	313	226	199	235	290	196	91
Np	4.67	4.72	4.16	4.19	4.64	4.92	4.78	4.87	4.84	4.88	3.93	4.39	4.55
Inc	3.7	4.4	3.8	3.6	3.5	3.4	3.5	3.3	3.5	3.5	3.7	3.4	3.4
Np2	.03	.02	.03	.09	.04	.12	.04	.05	.01	.04	.06	.25	.28
Pws	.99	1.00	1.00	.99	1.00	.77	.95	.84	.70	.44	1.00	.91	.81
Gw	.08	.02	.01	.09	.02	.59	.22	.33	.49	.86	.31	.23	.50
Nrwu	.14	.23	.05	.02	.09	.09	.10	.07	.15	.12	.05	.05	.08
Bt	.96	.95	1.00	1.00	.98	.99	.97	.97	.92	.99	.97	.99	.99
Sw1	.15	.11	.20	.22	.12	.07	.08	.10	.10	.04	.20	.10	.10
Sw2	.62	.58	.64	.65	.61	.64	.60	.72	.57	.63	.82	.62	.65
Wash	1.00	.99	1.00	1.00	.99	.99	1.00	1.00	1.00	1.00	.99	1.00	1.00
Tl	.70	.81	.96	.77	.26	.21	.19	.15	.25	.23	.40	.36	.14
Dw	.80	.82	.85	.96	.79	.97	.87	.94	.91	.92	.92	.93	.98
Spr	.63	.60	.80	.89	.72	.78	.74	.78	.69	.76	.77	.79	.80
Carw	.21	.23	.25	.35	.23	.44	.28	.42	.28	.33	.33	.34	.34
Othu	.11	.10	.16	.11	.07	.14	.07	.07	.08	.07	.07	.09	.07

Note: For explanation of symbols: see Table 24
District A,B,...,M: see Table 23 and Figure 20

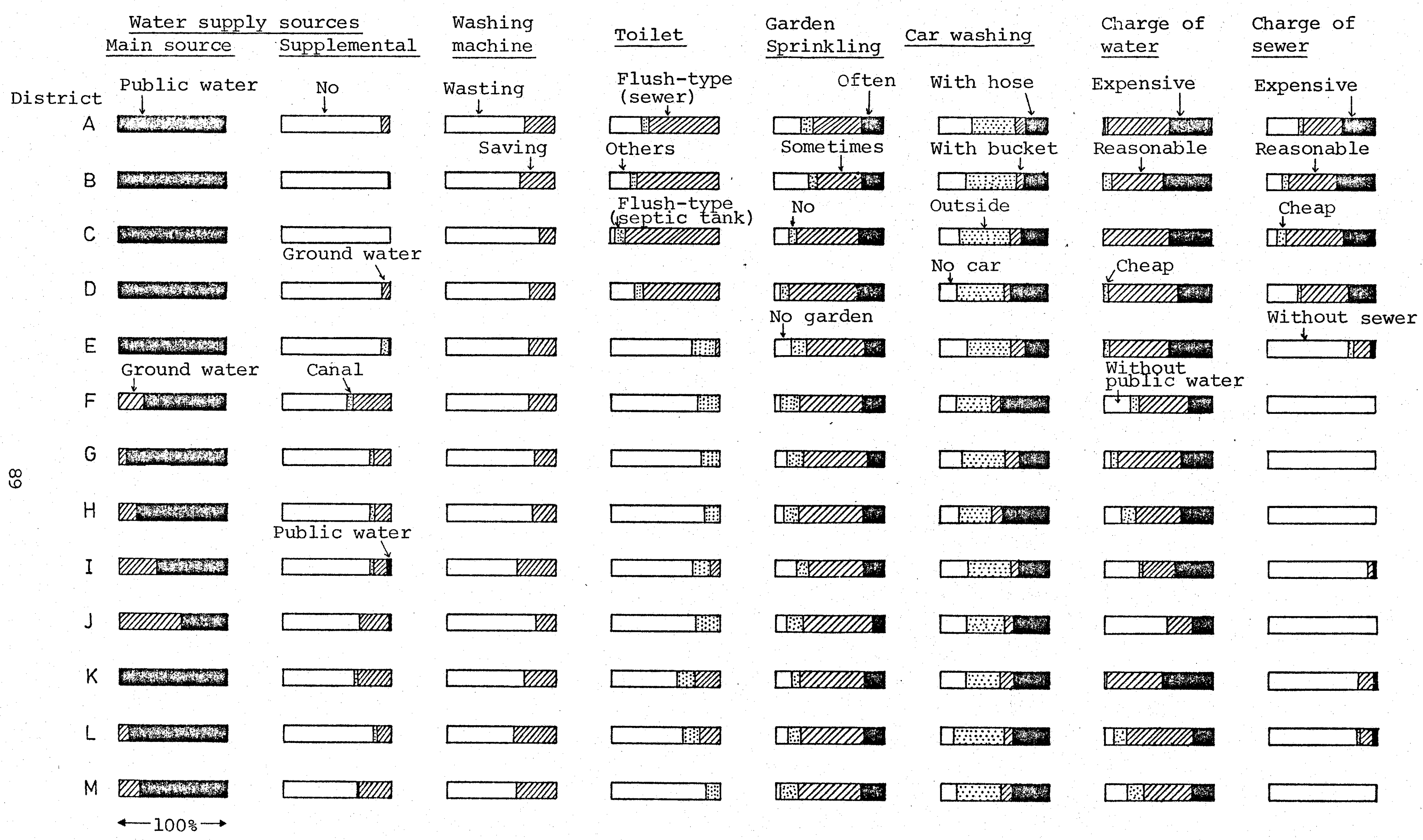


Figure 21 Results of qualitative variables of residential water use for Sample I

Note: District A,B,...,M: see Table 23 and Figure 20

Almost all of households have bath (Bt) and washing machine (Wash). Water-saving type of washing machine is used in about one fourth of households.

Flush-toilet (Tl) with public sewer is used more widely in the main part of Fukuyama city (A, B, C and D). In other urban and rural areas, flush-toilet is utilized in 14 % to 40 % of total households.

In the new residential areas (such as C, D and K), water-saving (Sw1: using water for bathing repeatedly) is done in more than 20 % of households. The used water for bathing is used for washing clothes in 57 % to 82 % of households (Sw2).

Single unit house (Dw) accounts for more than 80 % of total residences for each district.

The water is used for garden sprinkling in about 60 % to 90 % of residences, and is often used in one fifth of residences.

About three quarters of households have cars. Car washing with hoses is done in 21 % to 44 % of households and with bucket (water-saving) in 6 % to 13 % (Carw).

Only 7 % to 16 % of households have other types of water-using appliances such as pond, air conditioner and dish washer.

More than a half of households feel the charge of water and public sewer "reasonable", but 20 to 40 percent of households answer "expensive".

The mean values of Pws, Gw and Tl show the wide spatial differences, but there is no remarkable difference in the mean values of other variables.

The mean values of each variable for Sample II (the households with the available data on water use series) are given in Table 26. Mean values of water uses (Rwua, Rwus and Rwuw) are greater in the urban areas than in the rural areas. A comparison of two tables (Tables 25 and 26) shows that most of mean values of variables are very similar.

Bimonthly changes of water use for 1975 to 1977 (Sample II) are illustrated in Figures 22 and 23. The hights of the

Table 26 Mean values of variables for Sample II

District	A	B	C	D	E	F	G	H	I	J	K	L	M
No.	187	176	152	260	235	146	169	52	35	78	73	129	24
Np	4.76	5.03	4.18	4.25	4.65	4.88	4.82	4.52	4.49	4.81	3.93	4.37	4.92
Inc	3.7	4.3	3.8	3.6	3.6	3.3	3.7	3.3	3.0	3.5	3.7	3.6	3.6
Rwua	29.8	35.1	28.8	24.2	24.6	18.5	23.3	19.4	19.9	17.9	15.7	20.8	20.0
Rwus	32.2	45.9	33.1	29.4	31.1	21.1	31.4	25.4	25.8	24.4	21.0	26.9	25.9
Rwuw	23.0	29.3	21.6	19.7	19.9	12.6	17.5	15.3	14.8	14.4	12.3	17.1	15.2
Np2	.03	.02	.03	.07	.05	.13	.04	.00	.00	.06	.06	.25	.42
Pws	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gw	.09	.03	.01	.09	.03	.49	.17	.12	.18	.68	.31	.13	.50
Nrwu	.11	.23	.05	.02	.12	.08	.11	.06	.09	.17	.05	.05	.04
Bt	.97	.96	1.00	1.00	.99	1.00	.99	1.00	.91	1.00	.97	.99	1.00
Sw1	.13	.09	.23	.23	.12	.06	.05	.10	.09	.08	.20	.11	.04
Sw2	.64	.61	.64	.66	.63	.67	.64	.75	.72	.64	.82	.66	.63
Wash	.99	1.00	1.00	1.00	1.00	.99	1.00	1.00	1.00	1.00	.99	1.00	1.00
Tl	.71	.84	.96	.77	.26	.22	.14	.13	.34	.23	.40	.37	.17
Dw	.93	.95	.99	1.00	.90	.98	.93	1.00	.97	.96	.92	.95	.96
Spr	.72	.68	.92	.92	.76	.87	.80	.87	.80	.78	.77	.76	.75
Carw	.21	.22	.29	.37	.27	.44	.33	.37	.37	.39	.33	.34	.38
Othu	.11	.09	.18	.12	.08	.12	.08	.10	.03	.05	.07	.09	.08
Pw	.34	.40	.37	.31	.42	.27	.29	.42	.56	.45	.47	.18	.22
s/a	1.08	1.31	1.15	1.21	1.26	1.14	1.35	1.31	1.30	1.36	1.34	1.29	1.30
w/a	.77	.83	.75	.81	.81	.68	.75	.79	.74	.80	.78	.82	.76

Note: For explanation of symbols: see Table 24
District A,B,...,M: see Table 23 and Figure 20

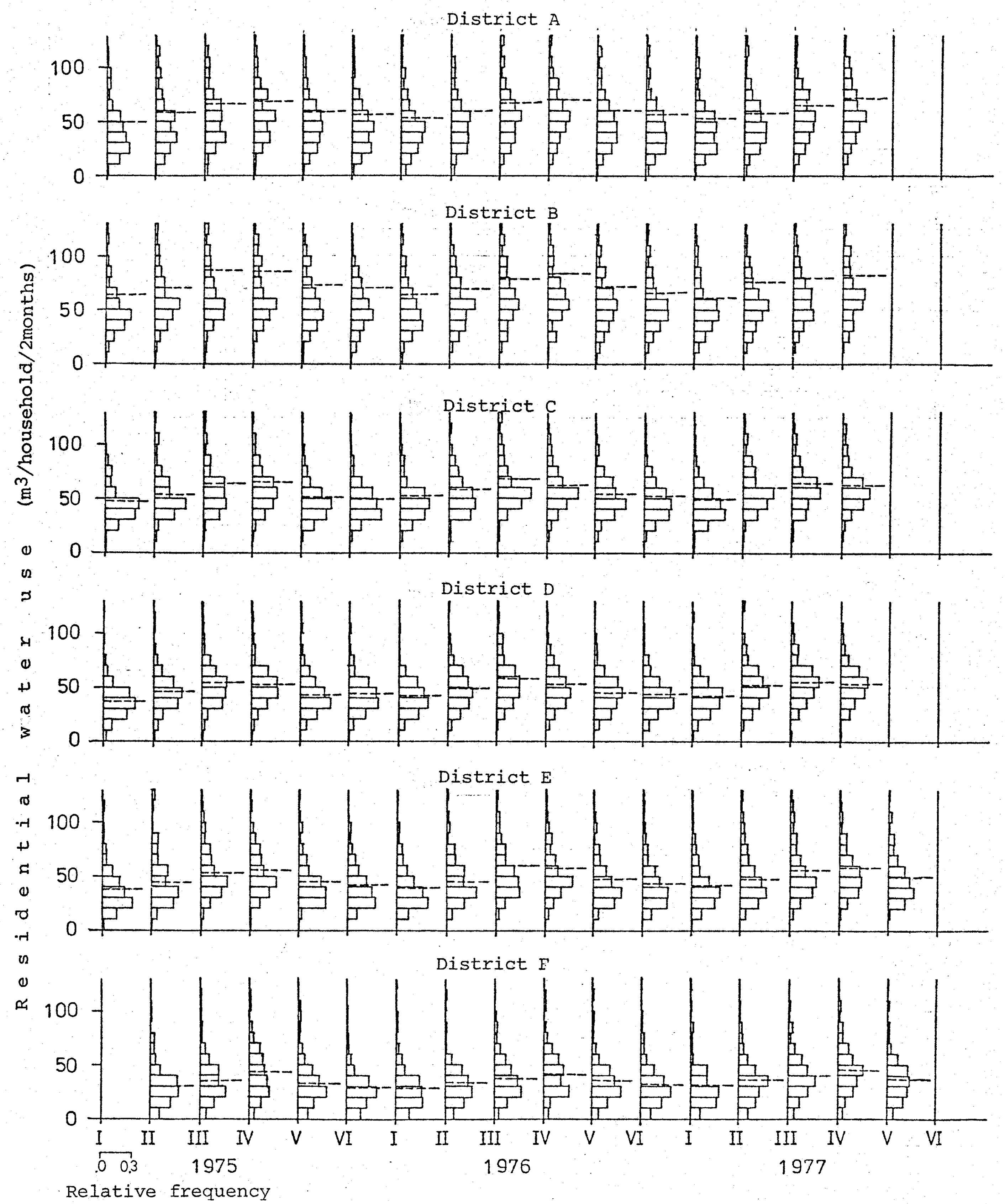


Figure 22 Distributions of residential water use series for Sample II

Note: District A,B,...,M: see Table 23 and Figure 20

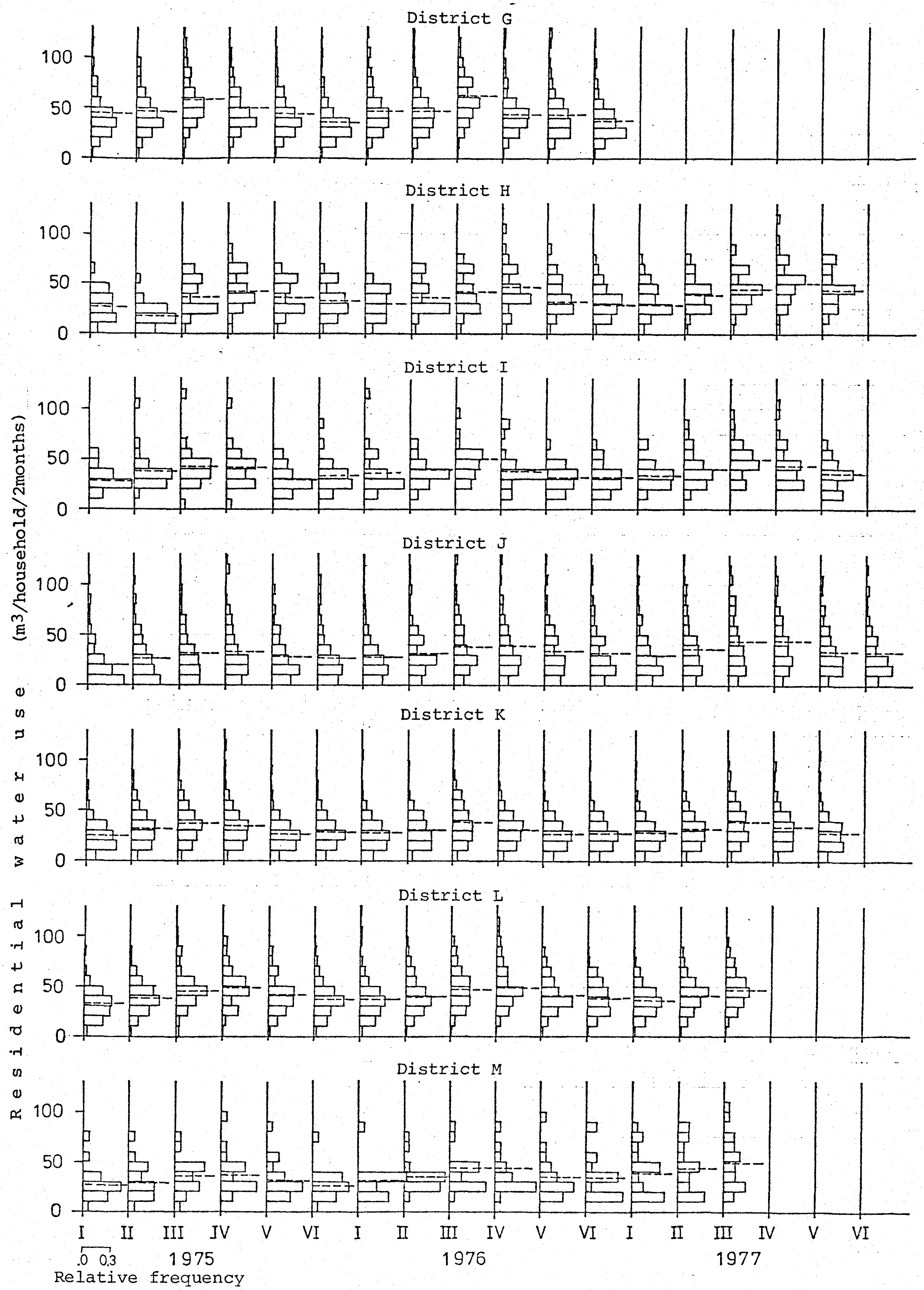


Figure 22 (continued)

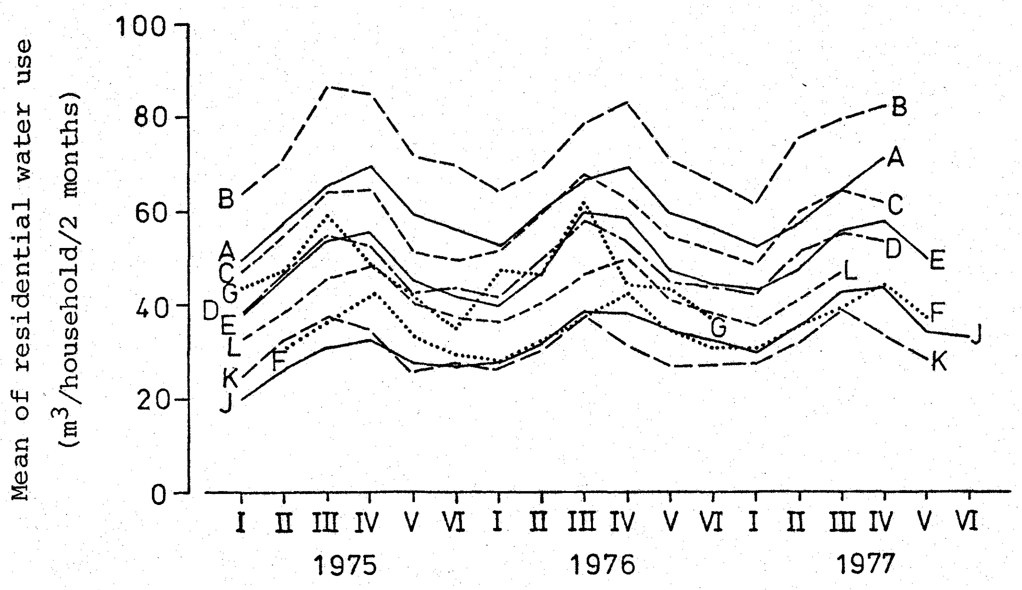


Figure 23 Mean values of residential water use series for Sample II
Note: Districts A,B,...,L: see Table 23 and Figure 20

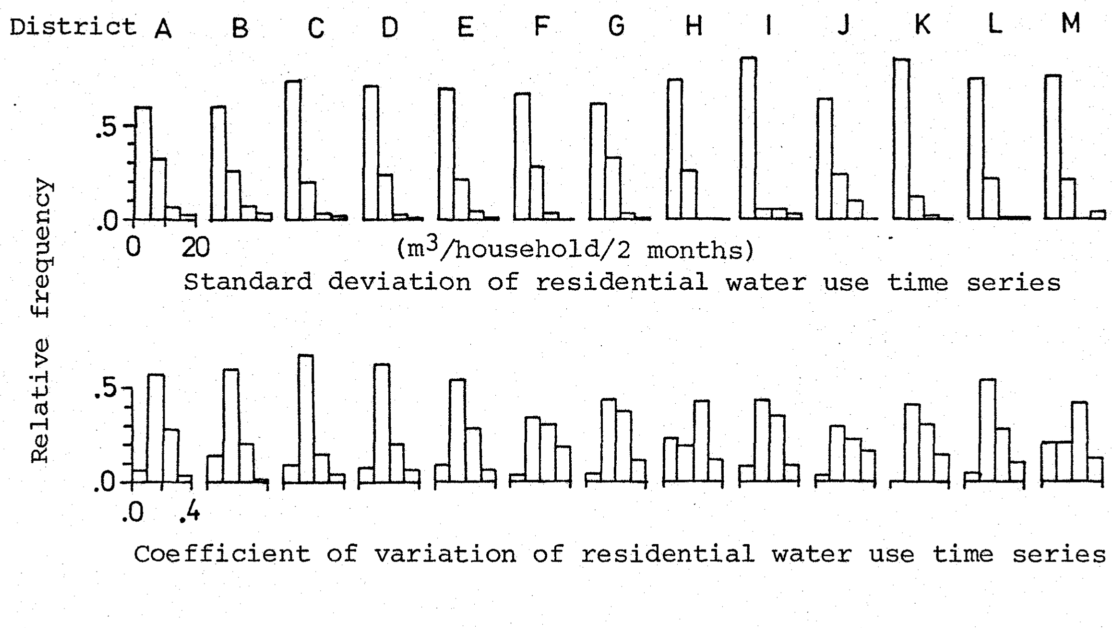


Figure 24 Standard deviations and coefficients of variation of residential water use series for Sample II
Note: Districts A,B,...,M: see Table 23 and Figure 20

various bars in Figure 22 indicate the relative frequencies in the various intervals. The water use series show evident seasonal fluctuations, and the major parts of households have the standard deviations of below 5 m^3/two months and the coefficients of variation of 0.1 to 0.3 (Figure 24).

Table 27 represents the seasonal variations given as bimonthly mean values divided by the annual mean for 1975 to 1977. The seasonal variations for residential water use show the minimum of 78 % to 87 % in winter and the maximum of 114 % to 130 % in summer. In general, the seasonal variations in water use are greater in the rural areas than in the urban areas.

Table 27 Seasonal variations of residential water use for Sample II from 1975 to 1977

District	Period					
	I	II	III	IV	V	VI
A	86	97	109	116	99	93
B	86	98	112	114	97	93
C	87	103	116	111	93	90
D	85	103	117	111	92	92
E	83	96	116	118	98	89
F	85	94	108	124	100	90
G	98	101	130	100	93	78
H	80	99	107	122	103	90
I	89	105	125	109	85	87
J	79	96	115	117	98	95
K	86	103	124	109	88	90
L	84	96	111	119	99	92
M	87	98	118	114	94	89

Note: A,B,C,...,M: survey districts; see Table 23 and Figure 20
I: February and March
II: April and May
III: June and July
IV: August and September
V: October and November
VI: December and January
Unit in percent.

(b) Factors affecting residential water demand for model A

The water demand functions are determined from sets of data for Sample III by surveyed districts. In the districts of H, I, J and M, however, the demand functions are not determined, because the observations used for this analysis are limited in number. Furthermore, the observations are divided into two subgroups: subgroup N in the lower basin (districts of A, B, C, D, E and L; 538 households) and subgroup O in the middle basin (districts of F, G, H, I, J, K and M; 257 households).

Table 28 lists the mean values of variables for Sample III. The mean values of water uses (Rwu and Rwc) are greater in the lower basin (subgroup N) than in the middle basin (subgroup O). There are wide differences in variables such as use of ground water (Gw) and use of flush-toilet (Tl).

Table 29 gives the simple linear correlations between the dependent variable and ten explanatory variables for Sample III. The better single indicators, each accounted for 25 % of variance of water use (that is, the simple correlation coefficient of more than 0.50), are Nrwu for districts A and B, Gw and Tl for district K, and Np for district L.

The regression analysis using model A for Sample III is listed in Table 30. Each regression equation is selected among all equations having every possible combination of a

Table 28 Mean values of variables for Sample III

District	No.	Rwu	Np	Np2	Gw	Nrwu	Bt	Wash	Tl	Dw	Othu	Inc	Rwc
A	71	338.3	4.94	.01	.13	.10	1.00	1.00	.72	.97	.13	3.1	68.5
B	75	391.7	4.95	.00	.03	.19	.97	1.00	.87	.95	.05	3.9	79.1
C	75	312.1	4.03	.00	.00	.03	1.00	1.00	.97	1.00	.21	3.3	77.4
D	143	292.1	4.27	.07	.03	.01	1.00	1.00	.83	.99	.13	3.1	68.4
E	83	273.8	4.72	.05	.04	.10	.99	1.00	.33	.94	.10	3.0	58.0
F	52	243.5	4.69	.12	.44	.12	1.00	.98	.29	.98	.13	2.8	51.9
G	76	264.4	4.71	.04	.17	.11	1.00	1.00	.12	.92	.09	3.2	56.1
K	57	197.7	3.96	.05	.30	.04	.98	.98	.40	.89	.05	3.3	49.9
L	91	251.8	4.36	.26	.13	.05	.99	1.00	.38	.96	.10	3.1	57.8
N	538	305.2	4.50	.07	.06	.07	.99	1.00	.69	.97	.12	3.2	67.8
O	257	236.1	4.54	.07	.26	.08	.99	.99	.24	.95	.08	3.0	52.0

Note: N: A,B,C,D,E & L O: F,G,H,I,J,K & M
For explanation of other symbols: see Table 24
District A,B,...,O: see Table 23 and Figure 20

Table 29 Simple correlation coefficients between residential water use (Rwu) and explanatory variables for Sample III

District	Np	Np2	Gw	Nrwu	Bt	Wash	Tl	Dw	Othu	Inc
A	.05	.03	-.04	.65	@	@	.04	.03	.11	.09
B	.27	@	.21	.61	.13	@	.24	.13	.04	.45
C	.15	@	@	-.10	@	@	.29	@	.17	.17
D	.10	.02	-.19	.03	@	@	.34	-.01	.21	.20
E	.45	.35	.18	.39	.11	@	.25	.09	.27	.21
F	.18	-.06	-.30	.41	@	.12	.49	.13	.20	.15
G	.26	.10	-.17	.17	@	@	.38	.07	.07	.05
K	.20	.37	-.55	.01	.00	.09	.55	.09	-.05	.10
L	.56	.21	-.27	.29	.14	@	.29	.12	-.02	.11
N	.27	.02	-.05	.46	.07	@	.26	.07	.09	.30
O	.18	.06	-.31	.29	.06	.08	.35	.03	.06	.09

Note: N: A,B,C,D,E & L O: F,G,H,I,J,K & M
For explanation of symbols: see Table 24
@ not available

Table 30 Residential water demand equations for Sample III (Model A)

Case	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	R	F	d.f.
A-1	289.2				497.8							.645	49.23**	69
A-2	300.1			-99.6	515.4							.661	36.36**	68
A-3	290.3			-123.4	517.8					99.1		.675	18.72**	67
A-4	227.7			-131.5	521.2					95.0	20.7	.685	14.60**	66
A-5	225.6		109.3	-130.3	522.7					96.5	20.7	.687	11.65**	65
A-6	151.9		185.0	-130.9	521.5				77.2	95.6	20.0	.689	9.62**	64
A-7	128.9	7.6	169.7	-137.3	521.2				63.3	92.9	20.2	.689	8.15**	63
A-8	131.4	6.8	171.3	-134.2	521.2			11.8	55.7	93.6	20.1	.690	7.03**	62
B-1	327.2				345.6							.611	43.52**	73
B-2	241.7				294.2						24.3	.667	28.86**	72
B-3	142.1				304.2			130.9			20.3	.696	22.18**	71
B-4	12.2	30.6			299.7			113.7			18.8	.715	18.26**	70
B-5	-50.0	28.5			295.0			118.9	71.4		19.1	.718	14.70**	69
B-6	-76.1	28.1			294.0	30.0		116.7	72.5		19.1	.719	12.09**	68
C-1	153.5							162.9				.294	6.90*	73
C-2	82.3	17.8						162.4				.328	4.34*	72
C-3	77.5	19.0						155.1		33.3		.361	3.55*	71
C-4	40.8	19.3						143.2		35.4	14.2	.387	3.09*	70
D-1	213.0							95.8				.340	18.43**	141
D-2	210.9							90.2		54.3		.379	11.72**	140
D-3	151.6							78.2		63.5	21.7	.410	9.38**	139
D-4	161.3			-74.9				70.3		66.2	21.4	.429	7.78**	138
D-5	109.0	11.6		-77.9				65.7		67.5	23.4	.438	6.52**	137
D-6	99.7	11.7	38.7	-73.7				69.7		70.2	24.2	.448	5.68**	136
E-1	18.3	54.1										.455	21.09**	81
E-2	7.6	53.8								123.8		.529	15.56**	80
E-3	-24.8	55.0						81.1		130.6		.599	14.76**	79
E-4	8.2	46.6			97.1			77.7		114.0		.631	12.89**	78
E-5	49.4	36.8	126.5		98.0			72.3		120.5		.657	11.67**	77
E-6	-2.9	36.1	134.0		104.5			59.4		108.6	19.8	.671	10.36**	76
E-7	-50.9	35.1	134.2		104.3	57.8		62.7		109.1	17.9	.672	8.83**	75

Table 30 (continued)

Case	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	R	F	d.f.
F-1	202.6							141.9				.489	15.70**	50
F-2	191.4				138.0			125.5				.590	13.09**	49
F-3	227.5			-79.8	144.5			120.0				.662	12.49**	48
F-4	28.2			-72.5	179.3		198.5	110.9				.688	10.55**	47
F-5	-39.5	14.5		-81.3	168.7		204.6	106.6				.702	8.95**	46
F-6	-95.4	17.3		-91.7	145.5		247.6	99.9		72.7		.721	8.11**	45
F-7	-158.7	15.2		-93.0	146.5		245.3	98.6	78.1	71.0		.725	6.96**	44
F-8	-177.7	14.6		-94.6	149.3		257.0	93.2	66.2	70.2	8.5	.728	6.05**	43
G-1	250.0							122.3				.375	12.13**	74
G-2	93.8	32.9						132.2				.482	11.02**	73
G-3	90.2	31.9			70.1			140.3				.522	9.01**	72
G-4	80.7	36.2		-80.5	108.8			130.6				.582	9.10**	71
G-5	64.8	36.5		-84.8	107.6			128.3			4.9	.585	7.28**	70
G-6	67.1	35.9	10.6	-84.7	106.7			128.5			4.9	.585	5.99**	69
K-1	155.1							105.4				.554	24.34**	55
K-2	190.2			-85.1				81.5				.682	23.46**	54
K-3	93.3	26.0		-102.6				78.8				.755	23.39**	53
K-4	85.5	24.8	129.6	-90.3				84.1				.814	25.53**	52
K-5	49.0	23.9	156.6	-93.9				74.9	48.6			.825	21.78**	51
K-6	66.5	23.8	156.3	-98.6				78.7	52.9		-6.6	.833	18.89**	50
K-7	42.9	24.2	155.9	-99.9		22.7		77.6	53.9		-6.6	.834	15.94**	49
K-8	35.1	24.0	155.9	-100.1		22.9	8.3	77.2	54.3		-6.6	.834	13.67**	48
L-1	83.9	38.5										.560	40.64**	89
L-2	80.3	37.8			120.4							.620	27.52**	88
L-3	61.8	37.2			119.7			55.3				.673	24.04**	87
L-4	76.1	36.4		-69.8	125.0			50.1				.712	21.95**	86
L-5	-120.2	36.9		-71.2	122.6	194.3		55.5				.737	20.22**	85
L-6	-154.7	36.4		-77.1	119.0	194.3		56.1			12.2	.746	18.53**	84
L-7	-174.8	36.0		-78.3	118.2	195.0		55.5	23.4		12.0	.747	14.97**	83
L-8	-186.3	34.5	9.3	-77.1	120.8	210.2		55.9	21.8		12.5	.748	13.03**	82
L-9	-186.2	34.5	9.3	-77.2	120.9	210.1		55.9	21.7	1.2	12.5	.748	11.44**	81

Table 30 (continued)

Case	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	R	F	d.f.
N-1	285.6				285.7							.463	146.38**	536
N-2	225.1				286.7			88.1				.532	105.64**	535
N-3	101.6	27.9			267.7			86.8				.569	85.08**	534
N-4	46.0	27.2			249.3			77.2			20.7	.595	72.86**	533
N-5	41.5	27.1			251.2			75.5		46.9	20.7	.602	60.61**	532
N-6	40.1	28.1		-57.9	253.0			71.4		49.7	21.5	.608	52.00**	531
N-7	-42.7	27.9		-58.2	252.7	84.9		71 7		48.9	21.3	.610	44.91**	530
N-8	-50.9	26.5	23.9	-56.4	254.5	95.6		73.6		49.3	21.4	.612	39.53**	529
N-9	-57.3	26.4	23.9	-56.6	254.3	95.9		73.4	6.9	49.1	21.4	.612	35.08**	528
O-1	213.9							93.6				.349	35.27**	255
O-2	249.0			-94.8	144.0							.464	34.81**	254
O-3	228.0			-84.7	137.4			79.8				.550	36.48**	253
O-4	120.8	24.6		-102.1	131.7			81.6				.607	36.84**	252
O-5	20.5	24.1		-101.3	136.3		102.9	80.5				.612	30.13**	251
O-6	22.2	23.5	19.5	-100.4	136.7		101.9	81.5				.614	25.26**	250
O-7	-14.2	23.6	19.1	-100.1	136.4	36.1	102.2	81.2				.615	21.64**	249
O-8	-17.5	23.5	29.3	-100.1	136.2	35.7	103.3	80.6			1.0	.615	18.87**	248

Note: R: the multiple correlation coefficient F: the variance ratio
d.f.: the degrees of freedom
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
A,B,.....,O: see Table 23 and Figure 20
1,2,...,9 in each case: the number of variables considered

Table 31 The "best" equations for Sample III (Model A)

	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	R	F	d.f.
A-6	151.9		185.0	-130.9	521.5				77.8	95.6	20.0	.689	9.62**	64
			(0.10)	(-0.19)	(0.68)				(0.06)	(0.14)	(0.11)			
B-5	-50.0	28.5			295.0			118.9	71.4		19.1	.718	14.70**	69
		(0.16)			(0.52)			(0.18)	(0.07)		(0.22)			
C-4	40.8	19.3						143.2		35.4	14.2	.387	3.09*	70
		(0.16)						(0.26)		(0.16)	(0.14)			
D-6	99.7	11.7	38.7	-73.3				69.7		70.2	24.2	.448	5.68**	136
		(0.09)	(0.09)	(-0.12)				(0.25)		(0.22)	(0.19)			
E-6	-2.9	36.1	134.0		104.5			59.4		108.6	19.8	.671	10.36**	76
		(0.30)	(0.21)		(0.23)			(0.21)		(0.24)	(0.15)			
F-8	-177.7	14.6		-94.6	149.3		257.0	93.2	66.2	70.2	8.5	.728	6.05**	43
		(0.15)		(-0.36)	(0.36)		(0.27)	(0.32)	(0.07)	(0.18)	(0.07)			
G-5	64.8	36.5		-84.8	107.6			128.3			4.9	.585	7.28**	70
		(0.34)		(-0.31)	(0.32)			(0.39)			(0.06)			
K-6	66.5	23.8	156.3	-98.6				78.7	52.9		-6.6	.833	18.89**	50
		(0.31)	(0.37)	(-0.49)				(0.41)	(0.18)		(-0.12)			
L-6	-154.7	36.4		-77.1	119.0	194.3		56.1			12.2	.746	18.53**	84
		(0.53)		(-0.26)	(0.27)	(0.19)		(0.27)			(0.11)			
N-7	-42.7	27.9		-58.2	252.7	84.9		71.7		48.9	21.3	.610	44.91**	530
		(0.20)		(-0.09)	(0.41)	(0.05)		(0.21)		(0.10)	(0.18)			
O-7	-14.2	23.6	19.1	-100.1	136.4	36.1	102.2	81.2				.615	21.64**	249
		(0.26)	(0.05)	(-0.39)	(0.32)	(0.03)	(0.08)	(0.31)						

Note: a_i: the regression coefficient — the value in parenthesis: the standardized regression coefficient
R: the multiple correlation coefficient — F: the variance ratio — d.f.: the degrees of freedom
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
District A,B,...,O: see Table 23 and Figure 20
1,2,...,7 in each case: the number of variables considered

given number of explanatory variables. A used criterion is to select the equation yielding the largest value of multiple correlation coefficient (R) and the expected signs of regression coefficients.

Table 31 represents the "best" equations for Model A which are no longer explaining a significant amount of the remaining unexplained variation by adding another variable. The standardized regression coefficients (A_1, A_2,..., A_{10}) are given by the following equation (Okuno, T., 1977).

$$A_i = a_i \ (S_{Xi}/S_{Rwu}) \quad \text{............................(18)}$$

where A_i is the standardized regression coefficient of variable X_i, a_i the regression coefficient of X_i, S_{Xi} the standard deviation of X_i, and S_{Rwu} the standard deviation of residential water use (Rwu).

The explanatory variables for model A are summarized in Table 32. The values represent the order of importance (that is, 1 represents the most important variable with the largest absolute value of the standardized regression coefficient, 2 the next,...). There are various combinations of important factors affecting residential water demand for each sample group. In general, the major factors affecting residential water demand are the number of persons in household (Np), the presence or absence of non-residential water use (Nrwu), of flush-toilet (Tl), and of other residential water use (Othu), and family income (Inc) in the lower part of basin. In the middle

Table 32 Explanatory variables for residential water demand for Sample III

District	Explanatory variables									
	Np	Np2	Gw	Nrwu	Bt	Wash	Tl	Dw	Othu	Inc
A		5	2	1				6	3	4
B	4			1			3	5		2
C	2						1		2	4
D	5	5	4				1		2	3
E	1	4		3			4		2	6
F	6		1	1		4	3	7	5	7
G	2		4	3			1			5
K	4	3	1				2	5		6
L	1		4	2	5		2			
N	3		6	1	7		2		5	4
O	4	6	1	2	7	5	3			

Note: N: A,B,C,D,E & L O: F,G,H,I,J,K & M
District A,B,...,O: see Table 23 and Figure 20
For explanation of other symbols: see Table 24
1,2,3,...: the order of importance (that is, 1 the most important variable with the largest absolute value of the standardized regression coefficient, 2 the next,...)

basin, the major factors are the number of persons in household (Np), and the presence or absence of ground water use (Gw), of non-residential water use (Nrwu), and of flush-toilet use (Tl).

(c) Factors affecting residential water demand for model B

The mean values of variables for Sample IV are listed in Table 33. Spatial differences in the mean values are found in the variables of residential water use (Rwu or Rwc), use of ground water (Gw) and use of flush-toilet (Tl).

Table 34 shows the simple linear correlations between the dependent variable and seven explanatory variables for

Table 33 Mean values of variables for Sample IV

District	No.	Rwu	Np	Gw	Bt	Sw1	Sw2	T1	Dw	Othu	Rwc
A	159	289.3	4.76	.08	1.00	.14	.65	.70	.93	.11	60.8
B	126	334.3	5.02	.02	1.00	.10	.64	.85	.94	.08	66.6
C	143	321.1	4.14	.01	1.00	.24	.66	.97	.99	.19	77.6
D	255	284.2	4.24	.09	1.00	.24	.66	.76	1.00	.12	67.0
E	200	264.4	4.55	.03	1.00	.13	.64	.23	.89	.07	58.1
F	131	217.7	4.85	.47	1.00	.06	.66	.21	.98	.09	44.9
G	147	253.5	4.75	.12	1.00	.05	.66	.14	.94	.05	53.4
H	49	228.9	4.47	.10	1.00	.10	.78	.12	1.00	.10	51.2
I	30	236.2	4.53	.10	1.00	.07	.70	.40	1.00	.03	52.1
J	63	185.4	4.76	.65	1.00	.08	.65	.19	.97	.06	38.9
K	67	197.5	3.88	.31	1.00	.21	.82	.40	.91	.04	50.9
L	119	245.5	4.37	.13	1.00	.12	.66	.36	.94	.09	56.2
P	97	209.5	4.08	.25	1.00	.16	.78	.40	.94	.04	51.3

Note: P: I & K
For explanation of other symbols: see Table 24
District A,B,...,P: see Table 23 and Figure 20

Table 34 Simple correlation coefficients between residential water use (Rwu) and explanatory variables for Sample IV

District	Np	Gw	Bt	Sw1	Sw2	T1	Dw	Othu
A	.30	-.09	@	-.08	-.16	.38	.06	.14
B	.38	-.09	@	-.08	-.10	.33	.13	.26
C	.27	-.03	@	-.17	-.14	.28	-.02	.31
D	.17	-.21	@	.00	-.12	.33	.01	.23
E	.43	.06	@	-.06	-.28	.36	.13	.17
F	.14	-.25	@	-.12	-.05	.49	.04	.03
G	.21	-.17	@	-.16	-.04	.39	.10	.29
H	.27	.01	@	.03	-.14	.29	@	.17
I	.13	.05	@	.14	-.23	.38	@	.19
J	-.02	-.41	@	-.08	.09	.22	.04	-.19
K	.22	-.49	@	-.01	-.12	.52	.08	.06
L	.47	-.18	@	-.12	-.10	.27	.11	-.02
P	.23	-.40	@	-.01	-.18	.47	.10	.08

Note: P: I & K
For explanation of symbols: see Table 24
@ not available

Table 35 Residential water demand equations for Sample IV (Model B)

Case	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	R	F	d.f.
A-1	217.9					101.3			.386	27.41**	157
A-2	89.6	28.3				92.1			.459	20.76**	156
A-3	88.0	25.8				100.5		68.7	.492	16.48**	155
A-4	78.1	28.6	-95.9			101.3		95.8	.530	15.01**	154
A-5	93.8	30.5	-93.9		-33.1	98.7		82.3	.545	12.90**	153
A-6	99.2	30.6	-94.3	-36.4	-34.6	98.7		85.0	.555	11.27**	152
A-7	113.8	31.8	-93.9	-35.9	-35.2	99.6	-22.5	86.2	.557	9.69**	151
B-1	130.5	40.6							.381	21.04**	124
B-2	70.8	34.6				105.8			.458	16.32**	123
B-3	76.2	33.4				96.8		107.5	.499	13.48**	122
B-4	94.1	34.9			-38.6	96.3		105.2	.515	10.90**	121
B-5	54.2	33.8			-37.5	97.6	46.3	102.7	.520	8.88**	120
B-6	56.8	33.2	-58.2		-35.0	95.6	48.0	108.1	.523	7.47**	119
B-7	59.8	33.1	-59.9	-16.3	-34.6	94.6	47.5	106.6	.524	6.39**	118
C-1	305.7							81.5	.312	15.16**	141
C-2	168.6					143.3		75.3	.403	13.61**	140
C-3	59.3	28.8				133.9		71.4	.465	12.76**	139
C-4	59.4	28.7		-46.8		145.8		70.0	.503	11.71**	138
C-5	82.0	29.4		-50.8	-31.5	142.0		68.9	.524	10.37**	137
C-6	122.5	29.5		-50.4	-32.0	141.5	-40.4	69.3	.525	8.62**	136
C-7	122.4	29.5	0.9	-50.4	-32.0	141.5	-40.4	69.3	.525	7.34**	135
D-1	223.0					80.0			.332	31.28**	253
D-2	221.0					73.4		60.3	.381	21.42**	252
D-3	145.5	17.8				73.8		59.6	.416	17.53**	251
D-4	150.0	19.9	-45.0			61.8		58.7	.432	14.35**	250
D-5	163.1	20.3	-43.7		-19.7	59.4		60.1	.442	12.05**	249
D-6	168.9	19.3	-44.7	-12.5	-19.9	61.2		61.0	.444	10.17**	248
D-7	168.6	19.3	-44.7	-12.5	-19.9	61.2	0.3	61.0	.444	8.68**	247

Table 35 (continued)

Case	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	R	F	d.f.
E-1	52.7	46.5							.431	45.03**	198
E-2	35.9	45.8				88.0			.554	43.57**	197
E-3	76.5	44.0			-50.2	85.0			.598	36.41**	196
E-4	77.7	43.1			-49.6	83.0		41.5	.606	28.34**	195
E-5	84.9	42.5		-26.7	-51.4	84.2		41.6	.612	23.27**	194
E-6	80.3	43.4	-31.9	-26.1	-49.9	85.8		45.3	.614	19.45**	193
E-7	81.5	43.5	-31.9	-25.9	-49.9	85.9	-2.4	45.5	.614	16.59**	192
F-1	190.4					127.7			.494	41.66**	129
F-2	212.2		-44.1			123.2			.536	25.76**	128
F-3	142.5	15.7	-56.4			119.0			.566	19.91**	127
F-4	138.0	16.5	-62.3			119.3		40.6	.576	15.61**	126
F-5	94.0	15.8	-63.8			120.1	48.9	50.0	.580	12.65**	125
F-6	94.8	15.7	-63.3	-14.5		119.0	49.5	40.1	.581	10.51**	124
F-7	94.9	15.7	-63.3	-14.5	-0.2	119.0	49.5	40.1	.581	8.93**	123
G-1	238.5					105.2			.389	25.92**	145
G-2	234.0					98.9		113.9	.466	19.94**	144
G-3	165.0	14.6				99.5		99.0	.493	15.31**	143
G-4	148.7	19.7	-57.2			94.6		95.8	.528	13.74**	142
G-5	154.7	19.1	-56.6	-55.6		94.4		93.2	.545	11.90**	141
G-6	158.9	19.2	-56.1	-55.9	-6.7	94.5		92.5	.546	9.90**	140
G-7	202.2	20.4	-53.4	-52.2	-8.5	95.5	-51.7	94.5	.561	9.11**	139
H-1	219.5					76.3			.294	4.43*	47
H-2	140.9	17.7				72.3			.384	3.99*	46
H-3	133.3	20.0	-29.2			74.0			.397	2.80	45
H-4	136.7	18.7	-30.5			72.3		28.4	.409	2.21	44
H-5	152.6	18.3	-36.6		-16.7	71.2		22.4	.415	1.79	43
I-1	210.8					63.4			.377	4.65*	28
I-2	243.2				-48.5	67.5			.463	3.69*	27
I-3	145.7	23.0			-63.2	76.3			.541	3.59*	26
I-4	145.2	23.4	-15.2		-63.9	78.2			.544	2.63	25
I-5	142.9	23.5	-25.1		-60.4	76.4		31.9	.547	2.05	24

Table 35 (continued)

Case	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	R	F	d.f.
J-1	254.7		-106.5						.410	12.34**	61
J-2	240.9		-100.1			50.5			.440	7.19**	60
J-3	74.0	19.3	-133.7				109.8		.462	5.35**	59
J-4	81.3	17.7	-126.0			40.3	97.2		.479	4.31**	58
J-5	105.4	16.7	-127.6	-39.1		36.8	82.2		.485	3.51**	57
K-1	157.2					100.0			.521	24.17**	65
K-2	188.7		-70.1			76.3			.612	19.19**	64
K-3	90.2	26.8	-84.8			74.2			.689	19.00**	63
K-4	89.1	25.9	-88.5			78.9		80.1	.710	15.78**	62
K-5	94.7	25.2	-89.4	-15.2		80.0		83.2	.713	12.63**	61
K-6	107.4	25.0	-89.5	-18.1	-12.8	78.6		85.6	.715	10.49**	60
K-7	109.3	25.0	-89.2	-17.9	-13.0	79.1	-2.5	85.9	.715	8.81**	59
L-1	117.9	29.2							.469	32.98**	117
L-2	89.5	30.8				59.6			.562	26.82**	116
L-3	92.7	31.9	-56.7			57.0			.598	21.33**	115
L-4	105.6	32.2	-54.8		-22.3	57.8			.609	16.79**	114
L-5	73.1	31.7	-57.0		-21.6	58.2	36.4		.616	13.81**	113
P-1	173.8					88.6			.470	26.92**	95
P-2	195.8		-67.1			75.2			.560	21.49**	94
P-3	97.2	24.2	-73.0			78.4			.635	20.99**	93
P-4	96.1	24.1	-83.0			78.8		90.9	.663	18.06**	92
P-5	117.1	24.4	-81.4		-27.9	77.3		88.8	.675	15.20**	91
P-6	119.6	24.2	-81.3	-6.2	-28.8	77.3		89.3	.675	12.56**	90
P-7	126.6	24.4	-80.8	-5.7	-29.4	78.3	-8.5	89.7	.675	10.66**	89

Note: R: the multiple correlation coefficient F: the variance ratio d.f.: the degrees of freedom
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
A,B,...,P: see Table 23 and Figure 20
1,2,...,7 in each case: the number of variables considered

Table 36 The "best" equations for Sample IV (Model B)

	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	R	F	d.f.
A-6	99.2	30.3	-94.3	-36.4	-34.6	98.7		85.0	.555	11.27**	152
		(0.27)	(-0.21)	(-0.11)	(-0.14)	(0.38)		(0.23)			
B-6	56.8	33.2	-58.2		-35.0	95.6	48.0	108.1	.523	7.47**	119
		(0.31)	(-0.06)		(-0.12)	(0.24)	(0.08)	(0.20)			
C-5	82.0	29.4		-50.8	-31.5	142.0		68.9	.524	10.37**	137
		(0.24)		(-0.21)	(-0.15)	(0.25)		(0.26)			
D-5	163.1	20.3	-43.7		-19.7	59.4		60.1	.442	12.05**	249
		(0.19)	(-0.12)		(-0.09)	(0.24)		(0.19)			
E-5	84.9	42.5		-26.7	-51.4	84.2		41.6	.612	23.27**	194
		(0.39)		(-0.09)	(-0.23)	(0.33)		(0.10)			
F-5	94.0	15.8	-63.8			120.1	48.9	50.0	.580	12.65**	125
		(0.19)	(-0.30)			(0.41)	(0.07)	(0.11)			
G-5	154.7	19.1	-56.6	-55.6		94.4		93.2	.545	11.90**	141
		(0.22)	(-0.20)	(-0.14)		(0.35)		(0.21)			
H-2	140.9	17.7				72.3			.384	3.99*	46
		(0.25)				(0.28)					
I-3	145.7	23.0			-63.2	76.3			.541	3.59*	26
		(0.30)			(-0.35)	(0.45)					
J-5	105.4	16.7	-127.6	-39.1		36.8	82.2		.485	3.51**	57
		(0.15)	(-0.50)	(-0.09)		(0.12)	(0.12)				
K-5	94.7	25.2	-89.4	-15.2		80.0		83.2	.713	12.63**	61
		(0.30)	(-0.44)	(-0.07)		(0.42)		(0.19)			
L-5	73.1	31.7	-57.0		-21.6	58.2	36.4		.616	13.81**	113
		(0.51)	(-0.20)		(-0.11)	(0.30)	(0.10)				
P-5	117.1	24.4	-81.4		-27.6	77.3		88.8	.675	15.20**	91
		(0.30)	(-0.38)		(-0.12)	(0.41)		(0.19)			

Note: b_i: the regression coefficient   the value in parenthesis: the standardized regression coefficient
R: the multiple correlation coefficient
F: the variance ratio   d.f.: the degrees of freedom
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
District A,B,...,P: see Table 23 and Figure 20
1,2,...,6 in each case: the number of variables considered

Sample IV. Sample IV is the observations for analysis using model B with two dummy variables on water-saving (Sw1 and Sw2).

The regression analysis of residential water demand for model B is presented in Table 35. Each equation is selected among all equations with a given number of explanatory variables on the basis of criterion as mentioned before. The "best" equations for model B and the standardized regression coefficients (B_1, B_2,...,B_7) are given in Table 36.

The explanatory variables for model B are summarized in Table 37. The values in this table present the same as in Table 32.

Table 37 Explanatory variables for residential water demand for Sample IV

	Explanatory variables						
District	Np	Gw	Sw1	Sw2	T1	Dw	Othu
A	2	4	6	5	1		3
B	1	6		4	2	5	3
C	3		4	5	2		1
D	2	4		5	1		2
E	1		5	3	2		4
F	3	2			1	5	4
G	2	4	5		1		3
H	2				1		
I	3			2	1		
J	2	1	5		3	3	
K	3	1	5		2		4
L	1	3		4	2	5	
P	3	2		5	1		4

Note: P: I & K
District A,B,...,P: see Table 23 and Figure 20
For explanation of other symbols: see Table 24
1,2,3,...: the order of importance (that is, 1 the most important variable with the largest absolute value of the standardized regression coefficient, 2 the next,...)

In general, the residential water use is affected by the variables of the number of persons in household (Np), the presence or absence of ground water use (Gw) and flush-toilet use (Tl) in the middle basin, and by the variables of the number of persons in household (Np), the presence or absence of flush-toilet use (Tl) and other residential water use (Othu) in the lower basin. A part of the variations in water use can not be explained by the variables used in this analysis.

(d) Factors affecting residential water demand for model C

The residential water demand functions including the price variable are determined from the cross-sectional data for Sample V. Sample V includes 673 households without babies, without non-residential water use, with bathroom (Np2=0, Nrwu=0, Bt=1). The demand functions are not determined for each surveyed district because of the limited number of available data sets for analysis. The present schedules for municipal water rate are indicated in Table 21.

Table 38 contains the mean values of variables and the regression analysis using model C for 673 households in the lower and middle basins, for 465 households in the lower basin, and for 208 households in the middle basin. Each equation is selected among all equations with a given number of explanatory variables on the basis of above mentioned criterion. All of the regression equations are

Table 38 Mean values of variables and residential water demand equations for Sample V (Model C)

Model C

$$Rwu = c_0 + c_1Np + c_2Gw + c_3Tl + c_4Othu + c_5Inc + c_6Pr$$

Variable		Rwu	Np	Gw	Tl	Othu	Inc	Pr	No.
	(Total)	266.2	4.42	0.11	0.56	0.10	3.15	59.1	673
Mean	(Lower)	284.8	4.41	0.06	0.71	0.12	3.20	57.5	465
	(Middle)	224.5	4.45	0.24	0.25	0.06	3.03	62.9	208

	c_0	c_1	c_2	c_3	c_4	c_5	c_6	R	F	d.f.
Total (except for M)										
1	211.5			96.8				.465	185.5**	671
				(0.47)						
2	113.5	22.2		96.4				.523	126.3**	670
		(0.24)		(0.47)						
3	114.0	24.9	-65.9	87.4				.558	100.9**	669
		(0.27)	(-0.20)	(0.42)						
4	111.8	24.8	-69.1	84.4	46.2			.574	82.3**	668
		(0.27)	(-0.21)	(0.41)	(0.14)					
5	92.9	24.5	-69.7	81.2	46.3	7.0		.580	67.6**	667
		(0.26)	(-0.21)	(0.39)	(0.14)	(0.08)				
Lower basin (A,B,C,D,E & L)										
1	220.4			91.0				.405	90.8**	463
				(0.40)						
2	120.7	23.1		87.9				.470	65.3**	462
		(0.24)		(0.39)						
3	116.0	23.4		85.8	40.3			.487	47.8**	461
		(0.24)		(0.38)	(0.13)					
4	116.1	24.4	-47.3	82.4	43.2			.498	38.0**	460
		(0.25)	(-0.11)	(0.36)	(0.14)					
5	88.1	24.3	-51.0	78.4	43.0	9.8		.510	32.2**	459
		(0.25)	(-0.11)	(0.35)	(0.14)	(0.11)				
Middle basin (F,G,H,I,J & K)										
1	203.8			84.1				.393	37.6**	206
				(0.39)						
2	220.1		-62.3	77.6				.485	31.6**	205
			(-0.28)	(0.36)						
3	104.9	26.5	-77.5	81.4				.595	37.3**	204
		(0.35)	(-0.35)	(0.38)						
4	123.8	26.7	-67.6	91.1			-0.4	.635	34.2**	203
		(0.35)	(-0.31)	(0.43)			(-0.23)			
5	125.5	25.8	-70.1	90.3	44.9		-0.4	.644	28.7**	202
		(0.34)	(-0.32)	(0.42)	(0.11)		(-0.23)			
6	123.1	25.7	-69.9	89.7	45.1	0.9	-0.4	.645	23.8**	201
		(0.34)	(-0.32)	(0.42)	(0.11)	(0.01)	(-0.23)			

Note: c_i: the regression coefficient
the value in parenthesis: the standardized regression coefficient
R: the multiple correlation coefficient
F: the variance ratio d.f.: the degrees of freedom
** Significantly different from zero at the 1 percent level.

significantly different from zero at the 1 % level. The regression coefficients of the price of water (c_6), however, show the negative sign only in the middle basin. The price of water does not affect water use in residence.

(e) Elasticities of residential water demand from cross-sectional data on individuals

In the linear demand function $Y = f(X_1, X_2, \ldots, X_i)$, the elasticity of demand (E_{X_i}) is given by the following function of Y and X_i.

$$E_{X_i} = (\partial Y/Y)/(\partial X_i/X_i) = (\partial Y/\partial X_i)/(X_i/Y) \ldots\ldots\ldots (19)$$

where ($\partial Y/\partial X_i$) is the regression coefficient of X_i. Here, the elasticity of demand is evaluated at the mean values of respective variables.

Table 39 Household-size, income and price elasticities of residential water demand from individual data

	Household-size elasticity			Income elasticity		Price elasticity
District	Sample III	IV	V	III	V	V
A	0.10	0.50	@	0.18	@	@
B	0.36	0.50	@	0.19	@	@
C	0.25	0.38	@	0.15	@	@
D	0.17	0.29	@	0.25	@	@
E	0.61	0.75	@	0.20	@	@
F	0.28	0.35	@	0.10	@	@
G	0.63	0.36	@	0.06	@	@
H	@	0.36	@	@	@	@
I	@	0.45	@	@	@	@
J	@	0.43	@	@	@	@
K	0.48	0.49	@	@	@	@
L	0.60	0.56	@	0.15	@	@
M	@	@	@	@	@	@
N	0.39	@	0.38	0.23	0.11	@
O	0.45	@	@	0.01	@	@
P	@	0.47	@	@	@	@
Q	@	@	0.51	@	0.01	-0.11
Total	@	@	0.41	@	0.08	@

Note: District A,B,...,Q: see Table 23 and Figure 20
Sample III, IV, V: see Table 23 @ not available
Elasticity of demand is evaluated at the mean.

Table 39 shows the household-size, income and price elasticities evaluated at the mean of respective variables. The household-size elasticities from cross-sectional individual data are in the ranges of 0.10 to 0.63 for Sample III, of 0.29 to 0.75 for Sample IV, and of 0.38 to 0.51 for Sample V. Income elasticities range from 0.01 to 0.25 for Sample III, and from 0.01 to 0.11 for Sample V. The price elasticity is -0.11 in the middle basin for Sample V.

(f) Price sensitivity of residential water demand

Responses to the following questions indicate the price sensitivity of water demand:

"Do you use water for bathing repeatedly?"

"Do you use the used water for washing clothes?"

"What do you think of the charge of water? Expensive, reasonable or cheap?"

Tables 40 and 41 present the answers to the above questions for 2,407 households which offer available data on price sensitivity of water. The three values in parenthesis on the left of Table 40 indicate the variables on the price of water (Pr), and water saving (Sw1 and Sw2). Pr is the answer for the third question and the values of 1, 2 and 3 denote "the price of water is cheap", "reasonable", and "expensive", respectively. In the sample of 2,407 households, 156 answer "the price of water is

Table 40 Relationship between the price of water and water-saving for households supplied with municipal water for each district

District	A	B	C	D	E	F	G	H	I	J	K	L	M	Total
No.	256	274	183	295	295	152	278	175	117	76	66	171	69	2,407
(1 0 0)	2	6	1	3	4	3	8	5	3	0	0	7	4	46
(1 1 0)	1	2	0	2	1	0	0	0	0	0	0	1	1	8
(1 0 1)	4	7	1	7	7	11	8	20	2	0	0	12	7	86
(1 1 1)	2	3	0	4	0	0	1	1	0	0	1	2	2	16
	9	18	2	16	12	14	17	26	5	0	1	22	14	156
(2 0 0)	45	56	26	45	53	31	64	21	19	17	5	41	12	435
(2 1 0)	8	6	12	15	5	3	6	4	3	1	1	3	1	68
(2 0 1)	77	63	60	98	93	60	98	55	27	25	24	65	21	766
(2 1 1)	15	10	10	24	13	1	9	4	2	0	3	5	5	101
	145	135	108	182	164	95	177	84	51	43	33	114	39	1,370
(3 0 0)	36	39	22	27	39	16	27	14	21	11	2	10	7	271
(3 1 0)	4	4	3	11	9	1	2	3	5	0	4	2	0	48
(3 0 1)	54	74	37	50	66	23	52	43	32	18	21	21	9	500
(3 1 1)	8	4	11	9	5	3	3	5	3	4	5	2	0	62
	102	121	73	97	119	43	84	65	61	33	32	35	16	881

Note: (Pr Sw1 Sw2) on the left of the table:
Pr=1 if the price of water is cheap, Pr=2 if reasonable, Pr=3 if expensive.
Sw1, Sw2=0 if the answer is "no", Sw1, Sw2=1 if the answer is"yes".
Districts A,B,...M: see Table 23 and Figure 20
Sw1 is done in 12.6 % of all households: see Table 24
Sw2 is done in 63.6 % of all households: see Table 24

Table 41 The obtained and the expected frequencies

	Price of water						
	Cheap (Pr=1)		Reasonable (Pr=2)		Expensive (Pr=3)		Total
Sw1 = 0	132	*136*	1,201	*1,198*	771	*770*	2,104
Sw1 = 1	24	*20*	169	*173*	110	*111*	303
Total	156		1,370		881		2,407
					$x^2 = 1.22$		
Sw2 = 0	54	*57*	503	*499*	319	*321*	876
Sw2 = 1	102	*99*	867	*871*	562	*560*	1,531
Total	156		1,370		881		2,407
					$x^2 = 0.70$		

Note: 132, 24,...: the obtained frequency
136, 20,...: the expected frequency
Sw1, Sw2: see Table 24

cheap" (Pr = 1), 1,370 "reasonable" (Pr = 2), and 881 "expensive" (Pr = 3). For Swl concerned with the first question, the values of 0 and 1 mean "no" and "yes" respectively. Sw2 is the answer for the second question, and the values of 0 and 1 mean "no" and "yes" respectively. A number of 303 households, representing 12.6 % of all 2,407 households, use water for bathing repeatedly (Swl=1). In the new residential areas (such as districts C, D and K), water saving (Swl=1) is done in more than 20 % of all households. A number of 1,531 households, representing 63.6 % of all households, utilize the used water for washing clothes (Sw2=1).

The hypothesis that the two descrete variables, water-saving (Swl or Sw2) and the price of water (Pr), are independent is tested at the 0.05 significant level. The obtained and the expected frequencies are shown for Swl and Pr (in the upper of Table 41), and for Sw2 and Pr (in the lower of Table 41). The chi square (x^2) statistic, which indicates the descrepancy between the obtained frequencies and the expected frequencies, is calculated. The larger the chi square statistic, the stronger is the independence in the sample. The values of the chi square statistic are 1.22 for Swl and Pr, and 0.70 for Sw2 and Pr. The obtained values of chi square are based upon two degrees of freedom. Since the obtained values are less than the appropriate value of 5.99 for the 0.05 level, the hypothesis is not rejected. The result suggests that there is no correlation between the price of water and water-saving, that is, the water is not considered as a commodity for household.

To ascertain the effect of the water rate increase on water use, the annual water uses before and after changing water rate are compared (Table 42). The old and the new water rate schedules and the percentage changes are given in Table 21. The water rates were risen about 60 % in Fukuyama and 30 % in Fuchu. There is a difference in reaction to price change among districts, that is, the reductions in water use are found in the districts of A, B, C and K, but not in the districts of D, E, F, H, I and L.

Table 42 Mean water uses before and after changing water rate schedule for Sample II

District	Mean water use: Before changing rate schedule	Mean water use: After changing rate schedule	Difference
A	364.1 (76.5)	360.7 (75.8)	-3.4 (-0.7)
B	438.1 (87.1)	437.1 (86.9)	-1.0 (-0.2)
C	344.8 (82.5)	342.3 (81.9)	-2.5 (-0.6)
D	288.3 (67.8)	291.5 (68.6)	+3.2 (+0.8)
E	288.7 (62.1)	298.0 (64.1)	+9.3 (+2.0)
F	203.8 (41.8)	214.5 (44.0)	+10.7 (+2.2)
H	217.9 (48.2)	233.6 (51.7)	+15.7 (+3.5)
I	222.2 (49.5)	226.2 (50.4)	+4.0 (+0.9)
K	184.9 (47.0)	181.2 (46.1)	-3.7 (-0.9)
L	250.3 (57.3)	254.1 (58.1)	+3.8 (+0.8)

Note: District A,B,..,L: see Table 23 and Figure 20
The values represent mean water use per household in m^3/household/year.
The values in parentheses represent mean water use per capita in m^3/person/year.

V DISCUSSION

In the preceding chapters, the water demands were analyzed in detail for various sectors. The present chapter contains the discussion based on the major findings of the past and the present investigations. The first section deals with several features of water demands and water management through pricing policy, and the second section contains change of residential water demand structure with urbanization.

5.1 Several Features of Water Demands and Water Management through Pricing Policy

(a) Variations in water use series

Water use series data fluctuate in different patterns of behavior. Irrigation water use series show evident seasonal fluctuations. Municipal water use series have steadily increasing trends and small seasonal fluctuations. Industrial water use series have rapidly increasing tendency and several striking depressions. These increasing trends in municipal and industrial water uses reflect the increasing number of use-units and industrial product. Negative jumps in water uses are found for municipal and industrial in summer of 1973. The depressions and negative jumps are not due to change in price of water, but due to droughts.

The seasonal variations in water use are different among the demand sectors from monthly series data of water use. The seasonal variations vary from 34 % - 67 % during the non-irrigation period to 163 % - 212 % during the irrigation period for irrigation, from 90 % in winter to 113 % - 116 % in summer for municipal, and from 89 % - 92 % in winter to 109 % - 111 % in summer for industrial. From the individual data, the seasonal variations of bimonthly water use range from 88 % to 107 % for industrial, from 85 % to 129 % for commercial and public, and from 78 % - 87 % in winter to 114 % - 130 % in summer for residential. Among commercial and public establishments, department store, large-scale shop, retail shop, restaurant, tea room, financial and insurance businesses, and school largely contribute to the summer increase in municipal water use, reflecting the uses of air conditioners and swimming pools. The slightly increase in industrial water use during summer is due to that the water is used repeatedly for product cooling and water use is restricted under drought conditions.

(b) Factors affecting water demands

An analysis of water demands using individual data indicates that there are wide differences in unit water use for different groups. For industrial water use, these differences were previously indicated by Shimazu, T. (1971), and they can not be fully explained by variables such as the type of manufacturing industry, the difference in industrial product, and the presence or absence of ground water use. There are also wide differences in unit water use for the types of commercial and public establishments. For schools, a portion of the variation in unit water use can be explained by the type of school, the presence or absence of water-using appliances (dormitory and swimming pool), and the number of teachers and students.

From a cross-sectional analysis of residential water demand, a significant portion of the variation in water use can be explained by the variables of the number of persons in household, the presence or absence of ground water use, the presence or absence of flush-toilet use and the presence or absence of non-domestic water use around the house. Almost all of households have bath and washing machine which require a large amount of water. The obtained results agree entirely with the earlier study of Tachikawa city (Shimmi, O., 1977).

The large unexplained portion of the variation suggests that water demands are markedly influenced by the factors, which are not considered in this analysis, such as the technological conditions and the way of water use. Therefore, there are great possibilities of reduction in water use by technological innovations and changing the way of water use.

(c) Elasticities of water demand

On the aggregated level, the elasticities of water demand with respect to the number of use-units or industrial product are around unity for industrial, and greater than unity for residential, commercial and public. It indicates that the unit water use increases for all sectors with the exception of industrial.

The income elasticity of residential water demand ranges from 0.01 to 0.25 for Sample III, from 0.01 to 0.11 for Sample V. Income does not explain the variation in water use. This figure is consistent with the elasticities derived in the past cross-sectional studies using individual data (Katzman, M.T., 1977; Shimmi, O., 1977), but lower than other studies (Grima, A. P., 1972; Morgan, W. D., 1973; Darr, P., et al., 1976; Gibbs, K. C., 1978). This difference is partly due to the fact that the assessed sales values of residence or the aggregated income data are used as individual income data by Grima (1972), Morgan (1973) and Gibbs (1978). The household-size elasticities are in the ranges of 0.10 to 0.63 for Sample III, of 0.29 to 0.75 for Sample IV, and of 0.38 to 0.51 for Sample V. These ranges are consistent with other cross-sectional studies (Grima, A. P., 1972; Morgan, W. D., 1973; Shimmi, O., 1977).

Analyses of annual and monthly water use series indicate that there is no significant reduction of water use reflecting water rate increase and water demand is not sensitive to price under the present price level. The price elasticity on the aggregated level is not calculated in all sectors with the exception of total use of Fukuyama municipal water use. The price elasticity is calculated as -0.25 and -0.45.

From a cross-sectional analysis of water demands by using the individual data, the price elasticity for residential is -0.11 in the middle basin. For other sectors, the price elasticities are not derived.

A comparison of mean water uses before and after increasing water rate indicates that the reduction of water use due to rate increase is not always recognized for all sectors or groups. For manufacturing industry, and commercial and public establishments, the water demand depends not so much upon the price of water as other variables. For residential, there is a difference in reaction to price change between the urban and the rural areas. Judging from the above results, the price elasticity of water demand is estimated as around zero at present.

For commercial, public and industrial water demands, these price elasticities are significantly lower than those derived in the cross-sectional studies using individual data (De Rooy, J., 1974; National Commission on Water Quality in the U.S.A.: see Lofting, E. M. and Davis, H. C., 1977; Lynne, G. D., et al., 1978). For residential water demand, previous cross-sectional studies using individual data provide different price elasticities of -0.93 (Grima, A. P., 1972) and of -0.51 to -0.62 (Gibbs, K. C., 1978), and cross-sectional studies using the aggregated data indicate the price elasticity of 0.01 to -1.24.

There are wide different results among the types of analysis and data for analysis (time series or cross-sectional analysis, aggregated or individual data). In general, the price elasticity derived on cross-sectional basis is greater than that on time series basis. The price elasticities on the aggregated level vary more widely than those on the individual level. This difference can be explained from the fact that cross-sectional data are devoid of dynamic information about the effects of price change on water use, and that the aggregated data do not always reflect the individual consumer response to price change.

(d) Water management through pricing policy

The pricing policy was proposed to be an effective tool for residential water management by Grima, A. P. (1972) and Yasui, M. (1975). The price elasticity of residential water demand on the time series basis is greater in the arid region than in the humid region (-0.49 in the arid region by Morgan, W. D., 1974; -0.1 to -0.2 and around zero in the humid region by Katzman, M. T., 1977 and in the present study, respectively). These different elasticities are explained from the fact that the sprinkling demand with high price elasticity constitutes a significant portion of residential water demand in the arid region and the domestic demand with low price elasticity constitutes a large proportion of residential water demand in the humid region.

In the U.S.A., the flat or the decreasing block rate structure is widely used. There is a vast difference in water use between metered and non-metered flat rate areas (Howe, C. W. and Linaweaver, F. P. Jr., 1967). The water demand was significantly reduced by the introduction of metering (Hanke, S. H., 1970; Russel, C., Arey, D. and Kates, R.: see Holtz, D. and Sebastian, S., 1978; Greenberg, M. R. and Hordon, R. M., 1976). The above facts are due to that the sprinkling demand with high price sensitivity constitutes a significant portion of residential water demand. Therefore, it is strongly required to change the rate structure from flat or decreasing block rate to increasing block rate.

In Japan, on the other hand, the flat and increasing block rate or the flat and uniform rate structure is adopted in most of municipalities. Because the domestic demand with low price sensitivity accounts for a large portion of total residential water use, the price elasticity for residential is calculated as around zero. The low price elasticity of demand suggests that the price of water does not affect the water demand and pricing policy is not an effective mean to modify water demand under the present low price. However, it may be an effective tool for water demand management under the high price structure or under the condition that the non-domestic demand with high price sensitivity accounts for a large proportion of total water use. There is a need for estimating the price elasticities under dynamic conditions for a large number of municipalities at different levels of water price.

Other useful means of modification of demand are done in the Ashida river basin. They are (1) reuse of water, (2) recycle of water, (3) technological innovations, and (4) restriction on water use under drought conditions in the lower level such as households, factories, commercial and public establishments.

5.2 Change of Residential Water Demand Structure with Urbanization

In this section, the temporal change of residential water demand structure is clarified on the basis of obtained results.

The Np and Rwu relations are determined by districts in order to consider an influence of urbanization, which is characterized by the increasing number of nuclear families, the spread of water-using appliances, and the change of supply source from ground water to public water, on residential water use. Model D represents the Np and Rwu relations.

$$Rwu = d_0 + d_1 Np \qquad (15)$$

where Rwu is the residential water use in household (m^3/household/year), Np the number of persons in household, and d_0, d_1 regression coefficients.

Table 43 contains the mean values of Rwu, Np, Gw, Bt, Tl and Rwc and the regression analysis for model D (Sample IV) for each survey district. Regression result of Tachikawa city is given in the earlier study (Shimmi, O., 1977). In general, the slope of Np-Rwu relation (d_1) is greater in the lower (urban) basin than in the middle (rural) basin. Spatial differences are found in the variables of Gw and Tl for Sample IV.

Table 43 The mean values of variables and the regression analysis for model D (Sample IV)

District	No.	Rwu	Np	Gw	Bt	Tl	Rwc	d_0	d_1	R	F	d.f.
A	159	289.3	4.76	.08	1.00	.70	60.8	128.1	33.9	.300	15.48**	157
B	126	334.3	5.02	.02	1.00	.85	66.6	130.5	40.6	.381	21.04**	124
C	143	321.1	4.14	.01	1.00	.97	77.6	182.5	33.5	.270	11.07**	141
D	255	284.2	4.24	.09	1.00	.76	67.0	209.1	17.7	.167	7.23**	253
E	200	264.4	4.55	.03	1.00	.23	58.1	52.7	46.5	.431	45.03**	198
F	131	217.7	4.85	.47	1.00	.21	44.9	162.1	11.4	.139	2.54	129
G	147	253.5	4.75	.12	1.00	.14	53.4	164.2	18.8	.212	6.85**	145
H	49	228.9	4.47	.10	1.00	.12	51.2	144.3	18.0	.266	3.57	47
I	30	236.2	4.53	.10	1.00	.40	52.1	189.4	10.3	.133	0.50	28
J	63	185.4	4.76	.65	1.00	.19	38.9	194.7	-2.0	.018	0.02	61
K	67	197.5	3.88	.31	1.00	.40	50.9	127.8	18.0	.217	3.22	65
L	119	245.5	4.37	.13	1.00	.36	56.2	117.9	29.2	.467	32.98**	117
P	97	209.5	4.08	.25	1.00	.40	51.3	132.7	18.8	.235	5.55*	95
Tachikawa@	250	248.5	3.77	.00	.86	.62	65.9	99.9	33.4	.483	75.80**	248

Note: A,B,...,P: see Table 23 and Figure 20
R: the multiple correlation coefficient
F: the variance ratio d.f.: the degrees of freedom
** Significantly different from zero at the 1 percent level.
* Significantly different from zero at the 5 percent level.
For explanation of other symbols: see Table 24
@: Regression result in Tachikawa city after Shimmi, O. (1977).

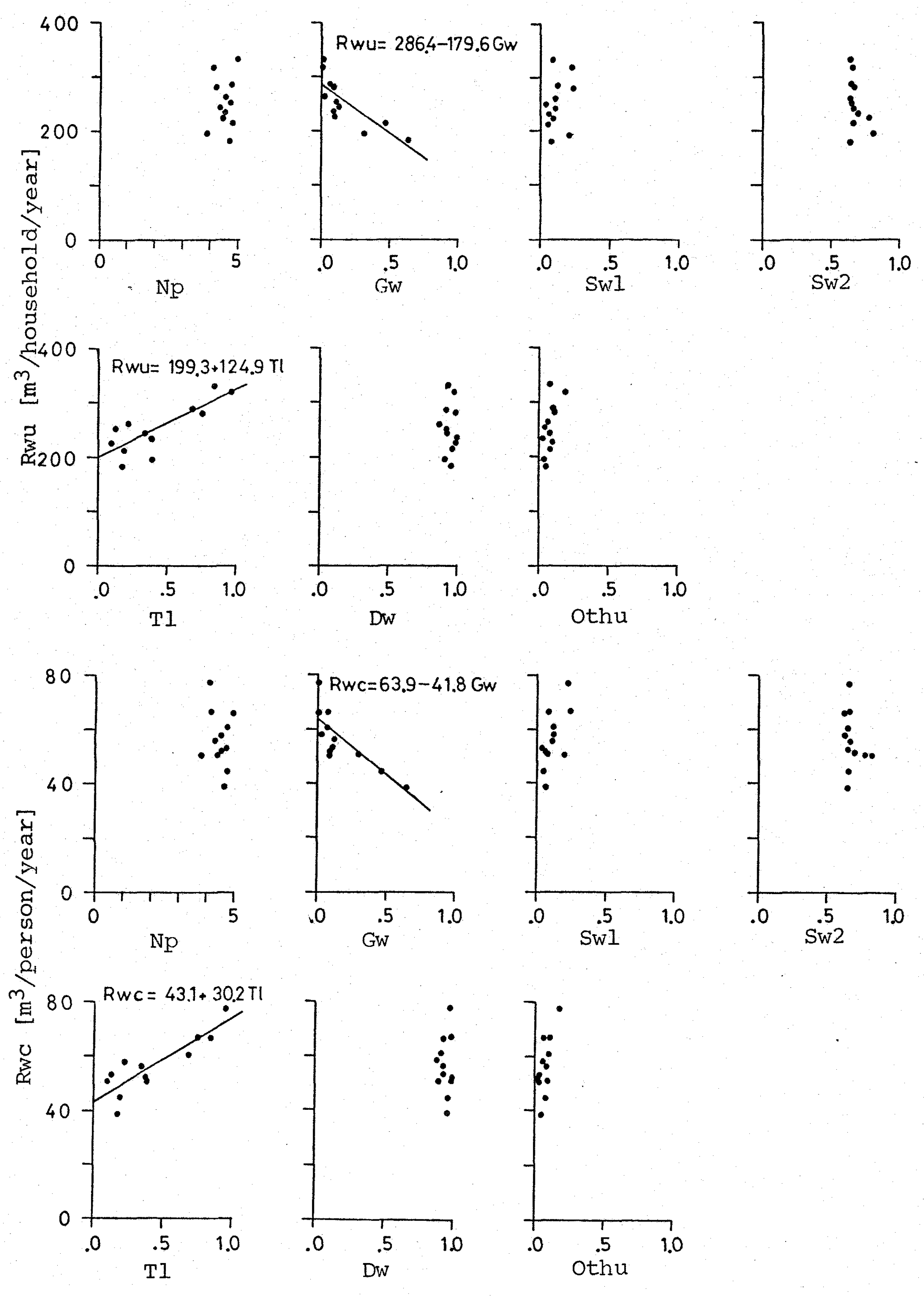


Figure 25 Relationship between residential water use and explanatory variables on aggregated level for Sample IV

For explanation of variables: see Table 24

The relations between the dependent and independent variables on the aggregated level are given in Figure 25, by plotting the mean values for sampling districts for Sample IV (Table 33). Higher correlations are found between water use (Rwu or Rwc) and Gw or Tl, but not between water use (Rwu or Rwc) and Np.

Figure 26 illustrates the plotted data of residential water use per capita (Rwc) as a function of the variables of ground water use (Gw) and flush-toilet use (Tl) for Sample IV in the Ashida river basin and Tachikawa city (Table 43).

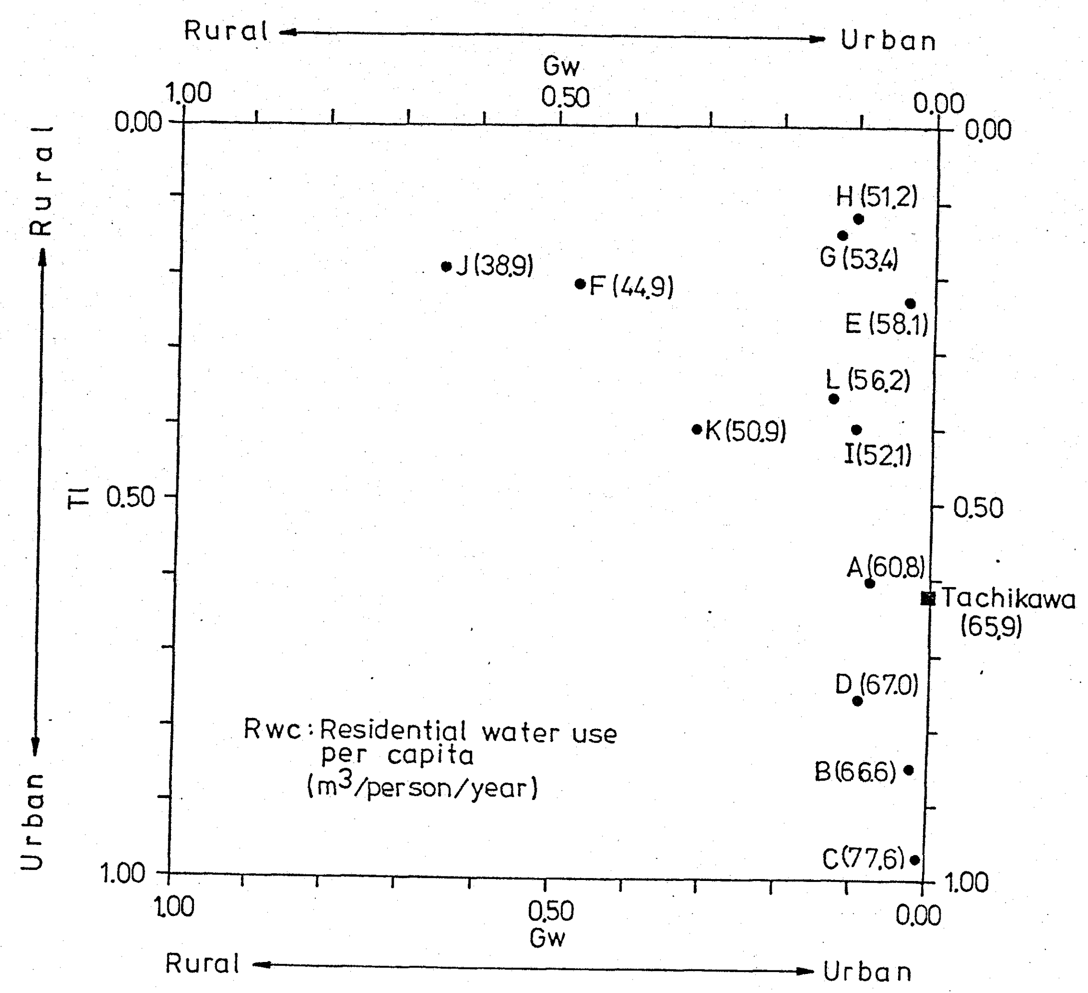


Figure 26 Residential water use per capita (Rwc) as a function of ground water use (Gw) and flush-toilet use (Tl) on aggregated level (Sample IV).

Note: District A,B,...,L: see Table 23 and Figure 20

The following demand function for model E is determined from the aggregated data on surveyed districts.

$$Rwc = e_0 + e_1 Gw + e_2 Tl \qquad (16)$$

where Rwc is residential water use per capita (m^3/person/year), given as Rwu divided by Np, Gw the ground water use, Tl the flush-toilet use, and e_0, e_1, e_2 are regression coefficients.

Table 44 contains the regression analysis and the mean values of Rwc, Gw and Tl on the aggregated level. The upper (1) is the demand function for 12 surveyed districts in this study area, and the lower (2) is the demand equation for 13 districts including Tachikawa city.

The model for 13 districts is

$$\hat{R}wc = 51.46 - 26.23\ Gw + 21.85\ Tl \qquad (17)$$

Almost all of the variations in water use per capita (Rwc)

Table 44 The regression analysis and the mean values of Rwc, Gw and Tl on the aggregated level for Sample IV

	Rwc Mean [S.D.]	Gw Mean [S.D.]	Tl Mean [S.D.]	e_0	e_1	e_2	R	F	d.f.
(1)	56.48 [10.05]	0.18 [0.19]	0.44 [0.29]	51.35	-25.91** (4.61)	21.79** (5.81)	.960	59.25**	9
(2)	57.20 [9.98]	0.16 [0.19]	0.46 [0.28]	51.46	-26.23** (4.98)	21.85** (6.12)	.962	62.49**	10

Note: e_i: the regression coefficient
the value in parenthesis: t-value
R: the multiple correlation coefficient
F: the variance ratio d.f.: the degrees of freedom
** Significantly different from zero at the 1 percent level.
(1) Districts A,B,C,D,E,F,G,H,I,J,K & L
(2) Districts A,B,C,D,E,F,G,H,I,J,K,L & Tachikawa (Shimmi,O.,1977)

can be explained by the two variables of ground water use (Gw) and flush-toilet use (Tl).

The observed values of water use per capita (Rwc) and the values calculated from the above equation ($\hat{R}wc$) are shown in Figure 27. The calculated value of $\hat{R}wc$ is less than the observed value in the new residential district of C, and greater than in the central part of cities such as districts A, B and I.

The spatial difference in residential water demand structure is summarized in Figure 28. It is possible to

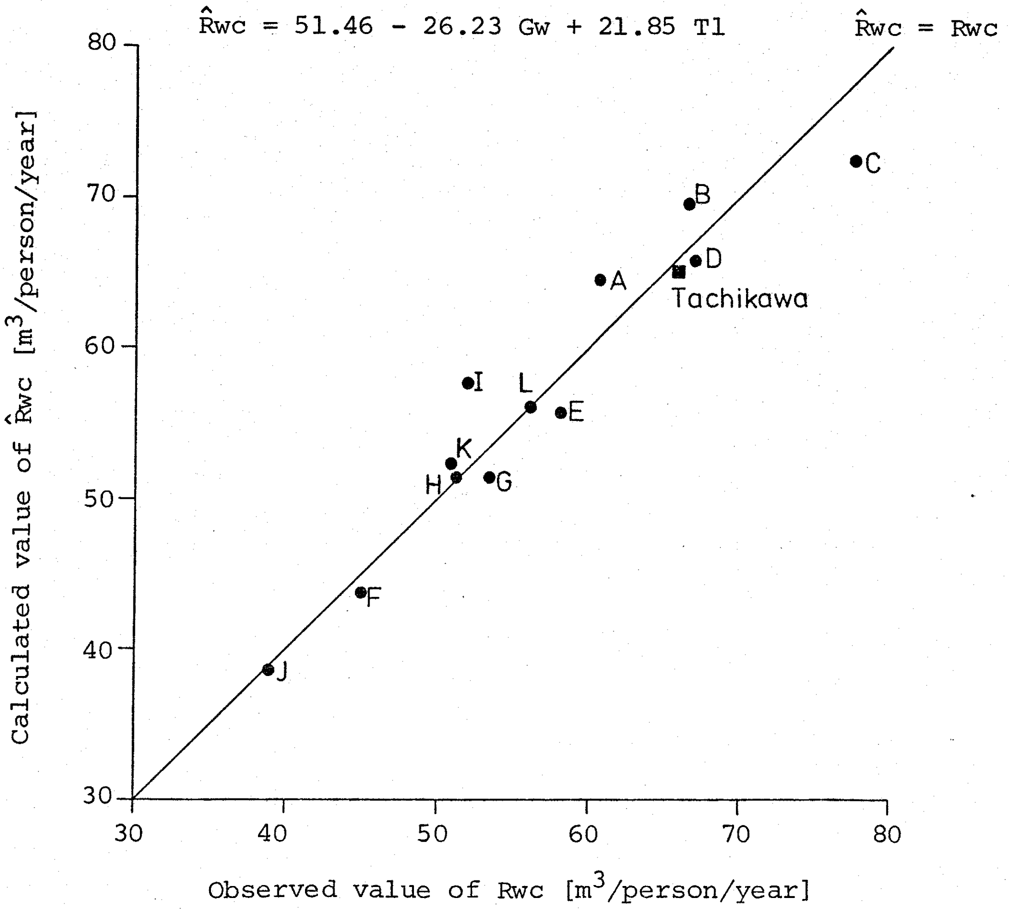


Figure 27 Comparison of observed and calculated residential water uses per capita from the aggregated data on surveyed districts
Districts A,B,...,L: see Table 23 and Figure 20

consider this spatial difference as the temporal change of demand structure. Urbanization with respect to the residential water use is characterized by the change of supply source from self-supplied ground water to public water, the spread of water-using appliances, the increasing number of nuclear families and so on. Relationship between the residential water use (Rwu) and the number of occupants (Np) is illustrated in the lower of Figure 28. The slope

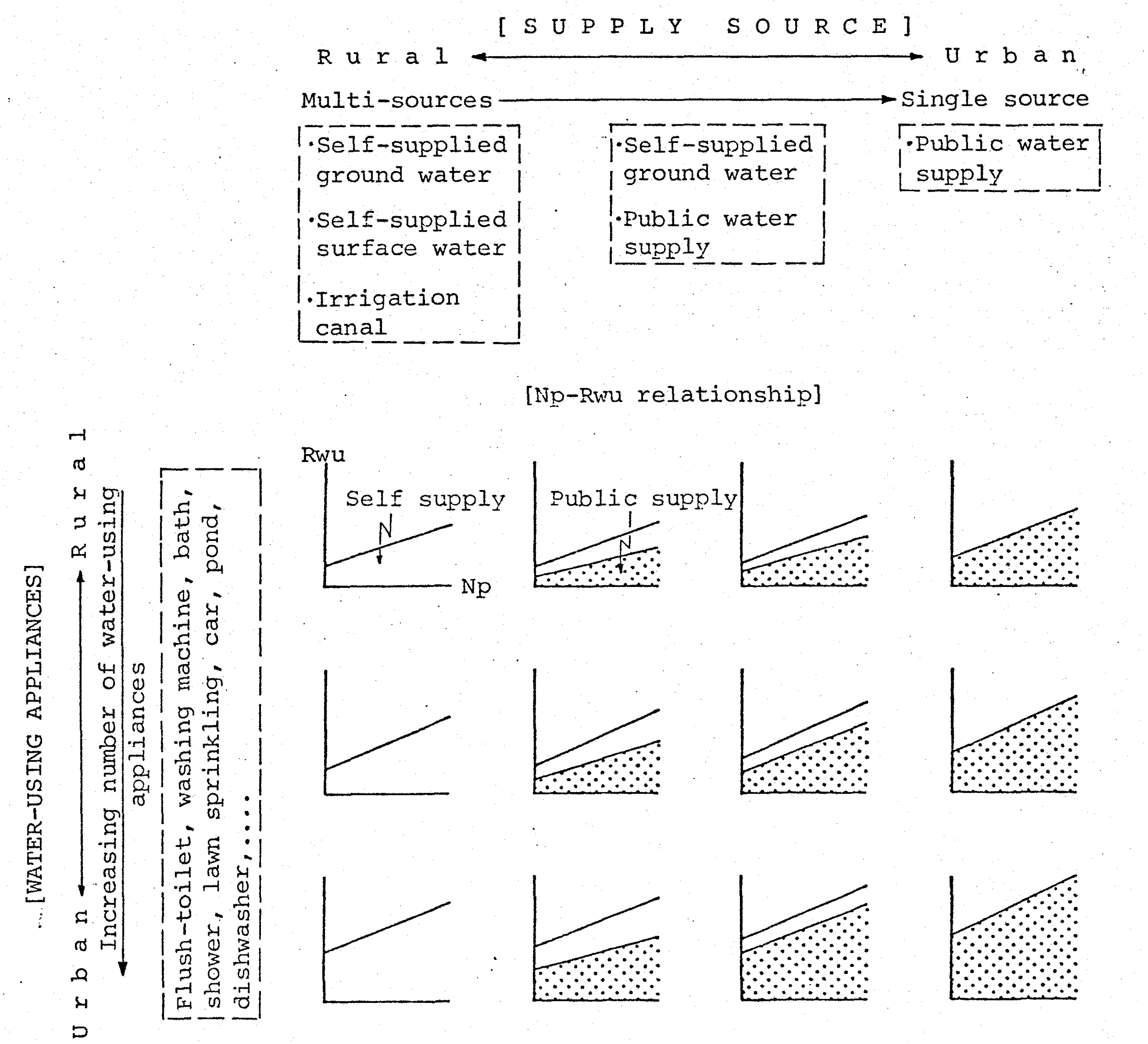


Figure 28 Spatial difference in residential water demand structure

of Np-Rwu relations (b_1) becomes steeper with the increasing number of water-using appliances and the decreasing amount of self-supplied ground water. With increasing number of nuclear families, residential water use in household (Rwu) slightly decreases, and residential water use per capita (Rwc) and the number of supplied households increase. Total of residential water use in the municipality, therefore, steadily increases. The household-size elasticity lies in the range of 0.3 to 0.7, and the income and price elasticities are around zero.

Because there is little possibility of introducing different kinds of water-using appliances, it is expected that the Np-Rwu relation in the urbanized area (Gw=0, Tl=1) does not significantly change. Further analysis both on cross-sectional and on time seires bases will provide the accurate information about temporal change of residential water demand structure.

VI SUMMARY AND CONCLUSIONS

In Japan, it has become difficult to solve the water supply-demand problems by increasing supply, and several regions are currently suffering from water shortage. However, there is little detailed information about actual conditions of water use. In the present study, the water demand structures in the Ashida river basin, one of the severe water-scarce areas in Japan, are clarified by using both the aggregated and the individual data.

The main stress is laid upon an analysis of residential water demand. The characteristics of variations in water use series are investigated by using the time series data on demand sectors. From the individual data obtained through the questionnaire survey conducted by the writer, the relevant factors affecting water uses are identified, the separate demand functions are determined, and the elasticities of demand for water are derived.

Stream water is the principal supply source for various water demands in the Ashida river basin. The rapidly growing industrial and municipal sectors have solved the water supply-demand problem by transferring water from agricultural sector. This water transfer was the pioneering work permitted on legal basis. Under drought conditions, the concerned users and municipal offices organized themselves into the committee on water allocation, and municipal water use was given a priority over other water uses.

The analysis of annual, monthly and daily series of water use leads to the following conclusions.

Irrigation water use series show evident seasonal variations. Municipal water use series have steadily increasing trends and small seasonal fluctuations. Industrial water use series have rapidly increasing tendency and several striking depressions. Negative jumps in municipal and industrial water uses are found in summer of 1973. On the basis of the determined demand functions for water, these increasing trends reflect the increasing number of use-units and the growing industrial production. The depressions and negative jumps are not due to change in price of water, but due to droughts.

A cross-sectional analysis of water demands using individual data leads to the following conclusions.

The seasonal variations of bimonthly water use vary from 88 % to 107 % for industrial, from 85 % to 129 % for commercial and public, and from 78 % - 87 % in winter to 114 % - 130 % in summer for residential. Among commercial and public establishments, department store, large-scale shop, retail shop, restaurant, tea room, financial and insurance businesses, and school largely contribute to the summer increase in municipal water demand.

There are significant differences in unit water use for groups of industrial, commercial and public establishments. For manufacturing industries, they can not be fully explained by variables of the type of industry, the difference in industrial product, and the presence or absence of ground water use. For schools, a portion of the variation in per capita water use can be explained by variables of the type of school, the presence or absence of water-using appliances (i.e., dormitory, swimming pool), and the number of teachers and students. The large unexplained portion suggests that water use is markedly influenced by factors of technological conditions and the way of water use, which are not considered in this analysis. Therefore, there are great possibilities of reduction in water use.

A significant portion of the variation in residential water use can be explained by the variables of the number of persons in household, the presence or absence of ground water use, of flush-toilet, and of non-domestic water uses around the house.

Income elasticity of 0.01 to 0.25 is consistent with that derived in the earlier study of Tachikawa city. Household-size elasticity of 0.10 to 0.75 is consistent with the previous cross-sectional studies based on individual data.

From time series data on demand sectors, the water demand is not sensitive to price and the price elasticity is calculated as -0.25 and -0.45 for Fukuyama municipal water use. For other sectors, the price elasticities are not derived.

From cross-sectional data on individuals, the price elasticity is calculated as -0.11 in the middle basin for residential, and it is not derived for industrial, commercial and public.

A comparison of mean water uses before and after water rate increase indicates that the reduction of water use is not always recognized for all sectors or groups.

The price elasticities of demand for water are estimated as around zero for most of sectors. These figures are significantly lower than those derived in the previous studies. The low price sensitivity indicates that pricing policy is not an effective mean to modify water demand under the present low price level. There is a need for estimating the price elasticities at different price levels.

There is a spatial difference in demand structure of residential water. Almost all of the variation in water use per capita can be explained by the uses of ground water and flush-toilet. It is possible to consider the spatial difference as the temporal change of demand structure.

Urbanization with respect to the residential water use is characterized by the change of supply source from self-supplied ground water to public water, the spread of water-using appliances and the increasing number of nuclear families. With the increasing number of water-using appliances and the decreasing amount of self-supplied ground water, both residential water use in household and that per capita significantly increase. With increasing number of nuclear families, residential water use in household slightly decreases, and both that per capita and the number of supplied households increase. Total of residential water use in the municipality, therefore, steadily increases. Because there is little possibility of introducing different kinds of water-using appliances, it is expected that the water demand structure does not change significantly in the urbanized area.

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APPENDIX A: INDUSTRIAL WATER USE QUESTIONNAIRES

1. Name of industry: ____________________
2. Address: ____________________
3. Person contacted: ____________________
4. Type of industry (Industrial classification by Census of Manufacture): ____________________
5. Principal products: ____________________
6. When was your original plant constructed at this site?
7. Total number of employees in plant today: ____________________
8. Industrial land acquired: ____________________
9. Value of products shipped: ____________________
10. Water utilization

Source of supply	Total	Industrial water use		
		Industrial boiler feed	Incorporate into product	Product cooling
Industrial water supply				
Municipal water supply				
Self-supplied surface water				
Self-supplied ground water				
Recirculated water				
Self-supplied sea water				

(Quantities used in plant operation)			Sub total	Non-industrial water use
Washing Process	Air conditioning	Others		

APPENDIX A (continued)

11. Do you recycle water for plant operation?

12. Do you have flush-toilet?

If yes, indicate the type of flush-toilet by checks.

High tank with public sewer   High tank with septic tank
Low tank with public sewer   Low tank with septic tank

13. Do you have?

Cooling tower for air conditioning?
Dining room?   Swimming pool?   Pond?
Bathroom?   Car washer?   Garden splinkler?
Washing machine?   Other water-using appliances?

14. Water return (Indicate by checks)

	Industrial water use for plant operation	Non-industrial water uses
Public sewer after treating		
Surface water after treating		
Public sewer non-treating		
Surface water non-treating		

15. Do you make any efforts to save water?

16. Has your establishment ever been affected by a water shortage?

If yes, what made you aware of the shortage? And when?

APPENDIX B: COMMERCIAL AND PUBLIC WATER USE QUESTIONNAIRES

1. Name of establishment: ______________________________
2. Address: ______________________________
3. Person contacted: ______________________________
4. Type of establishment: ______________________________
5. When was your work established?
6. Land aquired and floor space: ______________________
7. Total number of workers: ______________________
8. Number of guests, students and patients: ____________
9. Supply source and water utilization

Source of supply	Quantities used	Purpose
Industrial water supply		
Municipal water supply		
Self-supplied surface water		
Self-supplied ground water		
Recirculated water		
Self-supplied sea water		

10. Do you have flush-toilet?

    If yes, indicate the type of flush-toilet by checks.

    High tank with public sewer　　High tank with septic tank
    Low tank with public sewer　　Low tank with septic tank

11. Do you have?

    Cooling tower for air conditioning?
    Dining room?　　Swimming pool?　　Pond?
    Bathroom?　　Car washer?　　Garden sprinkler?
    Washing machine?　　Other water-using appliances?

12. Water return (indicate by checks)

    Public sewer after treating　　Surface water after treating
    Public sewer non-treating　　Surface water non-treating

13. Do you make any efforts to save water?
14. Has your establishment ever been affected by a water shortage?

    If yes, what made you aware of the shortage? And when?

15. Only for hotel and motel (Indicate by checks)

    Number of rooms: ____________

    Bathroom:　　Common use　　Individual use

    Toilet:　　Common use　　Individual use

APPENDIX C: RESIDENTIAL WATER USE QUESTIONNAIRES

1. Name:__________________________

2. Address:____

3. How many people live in your house?

4. How many living-out employees and day scholars live in your house?

5. How many babies under two years old live in your house?

6. Main and sub water supply sources (Indicate by checks):
   Public water supply　　Self-supplied ground water
   Irrigation canal and runnel

7. Do you use water for non-residential purposes?

8. Do you have a bath tub?
   If yes, how often do you bathe in the summer?　　In the winter?
   If yes, do you use water for bathing repeatedly?
   If yes, do you use the used water for washing clothes?

9. Do you have a washing machine?
   If yes, indicate the type of washing machine by check.
   Water-saving type　　Water-wasting type

10. How often do you wash clothes in a week?

11. Do you make any efforts to save water for washing?

12. Type of toilet (Indicate by checks):
    Flush-toilet with public sewer　　Flush-toilet with septic tank

13. Type of dwelling unit (Indicate by check):
    Single unit house　　Apartment house

14. How often do you water your garden?

15. Do you have a car?
    If yes, indicate the way of car washing by check.
    With hoses in your house　　With a bucket in your house
    Outside of your house (i.e., gas station, etc.)

16. Do you have other water-using appliances?

17. How much is the charge of water?

18. What do you think of the charge of water? (Indicate by check)
    Expensive　　Reasonable　　Cheap

19. How much is the charge of public sewer?

20. What do you think of the charge of public sewer? (Indicate by check)
    Expensive　　Reasonable　　Cheap

21. How much is your family income?

22. Indicate the series data of water use.