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Hydrological Characteristics and Projected Demand-Supply of Water Resources in Korea

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Synopsis

Variation pattern and stochastic characteristics of rainfall and streamflow are given as the hydrologic characteristics of water resources in Korea, and the projection of water demand is made from the estimation of present and future consumptive use and loss of water for municipal and domestic, manufacturing, agricultural, and other purposes. This projected water demand is compared with the deputable water supply to get a water demand-supply relationship in the projected time period. The present progress of water resources development in Korea is then discussed.

Introduction

It is observed that every country in the world has continued to be engaged in expanding its industrial activities to suit its national circumstances for the promotion of the welfare of its people. These activities involve water which joins such premier elements of human life as land and air to play a most vital role for the well-being of mankind.

The problem of water once involved only floods caused by excess runoff and droughts caused by lack of water. However, it has come to assume a completely different and far more vital role as man has recklessly destroyed and polluted the national environment all over the world to such an extent that nature's ecological equilibrium has been disturbed and its restorative capability critically threatened. In this respect, Korea is by no means unique.

Korea is faced with a rapidly rising demand for water for its growing population, urbanization, industrial development particularly of water-consuming types and raising of living standards. All these elements call for the preservation of water in quantity and in quality to meet the nation's immediate demand. Its water problem thus is two-fold: diminishing source. and increasing pollution, and involves development and preservation of a vital resource beyond the conventional water control and utilization schemes of yesteryear.

The average annual precipitation over the country is 1,159 milimeters which produce 114 billion tons per annum. These figures may give the impression that the water resources in Korea is well above the world average. However, two thirds of the annual precipitation is falling in the months of July and August. In consequence, the country suffers from severe flood damage in rainy seasons as well as drought in non-rainy seasons. The country also remains among the less blessed in terms of per capita rainfall, which standing at 3,200tons per capita per annum is only 10% of the world average of 32,000tons.

Of 114 billion tons of total annual precipitation, 44.7% (51 billion tons) is lost as evaporation and infiltration, and the remaining 55.3% (63 billion tons) is the amount of water flowing into rivers in annual runoff volume. Of this 63 billion tons of total river runoff as usable water resource, 61.9% (39

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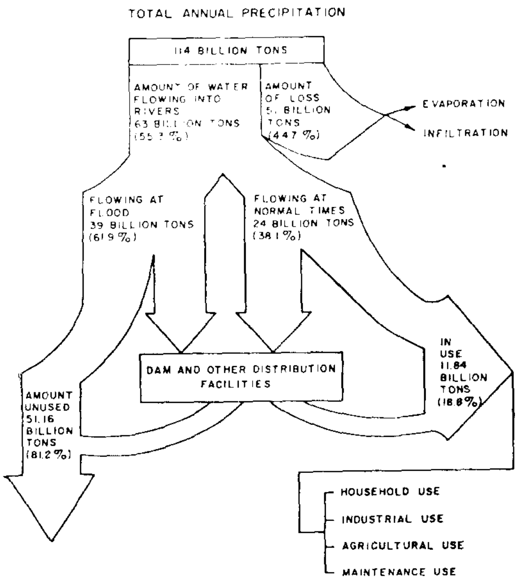

Figure 1. Water Balance in Korea

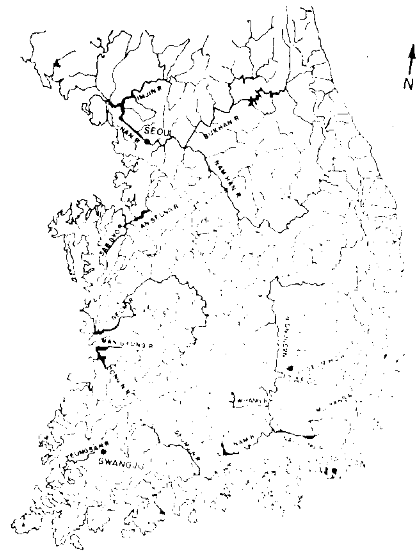

Figure 2. Watersheds in Korea

billion tons) is being wasted as flood discharge, and only the remaining 38.1% (24 billion tons) feeds the country's rivers (given in Figure 1. in details). Furthermore, the fluctuation of this river runoff is pronounced seasonally and it calls for appropriate means, such as dams, reservoirs and systematic water resources management, for year-round stabilization of water use.

With the problems ahead as briefly mentioned the issue of water resources in Korea should seem to be dealt with appropriate means of planning and management which are based on its characteristics and natures. Therefore, hydrological and future demand-supply characteristics of water resources are discussed with the present progress of its development in this paper.

Hydrological Characteristics

Watersheds and Hydrological Data

The water management areas in Korea is commonly divided into five watersheds according to the size of the watersheds. Among them, four major watersheds (Han, Nakdong, Geum and Yeungsan river basin) cover 64% of the whole country which is 98,477 square kilometers, and the remaining watersheds are composed of several small watersheds which hold minor significance in water management. General features of watersheds are shown in Figure 2. Since the total watershed area is relatively small, most of the rivers have small drainage areas and short river lengths with steep slopes which have generally the following relationship (Choi, et. al., 1979):

$$A = 0.42L^{1.75} \qquad \cdots\cdots(1)$$

where A is drainage area in square kilometers and L is river length in kilometers.

Therefore, the river stage rises abruptly as soon as it rains, causing frequent floods. Moreover, the variability of streamflow is very great due to the seasonal variation of rainfall.

For these reasons, the history of hydrological observations in Korea has started in the early 15th century. The rainfall gage which is known to be one of the oldest gages in the world was installed in 1441. It is believed that Korea is one of the very few countries which have more than 300 years precipitation records.

As of today, modern equipments for the measurement of precipitation and river stage and discharge were installed over the whole country, and the density of the rain gages reached to one in 400 square kilometers on the average. The following table shows the present hydrological network of the country:

Table-1. Hydrological Network in Korea

Observation Items	Water level			Precipitation			Discharage and Sediment
Type	Recording	Ordinary	Total	Recording	Ordinary	Total	
No. of Stations	54	127	181	144	96	240	22

In addition to the above hydrological network under the Ministry of Construction, several other governmental and research organizations have installed and operated the supplemental hydrological networks for their own works.

One example of automatic and systematic hydrological data collection is Han river basin's flood warning system in which an automatically recorded rainfall and river stage data upstream in the basin is transmitted to the computer installed at the downstream to use in the floodwarning system.

Variation Pattern and Stochastic Characteristics

The annual variation of precipitation is so wide seasonally as well as regionally that precipitation, mainly rainfall, is concentrated to fall in the summer rainy season between June and September. In this season the typhoon especially brings heavy rainfalls and causes serious flood damages in consequence because it accompanies wet air mass from the South Pacific. However, there occurs comparatively little rainfalls during other seasons. The variation of nation-wide mean monthiy rainfall is shown in Figure 3.

On the other hand, the variability of streamflow is also characterized by the same pattern as the rainfalls which can be seen from Figure 4. This high fluctuation of river flows is due to the above mentioned watershed characteristics as well as seasonal variation of rainfall.

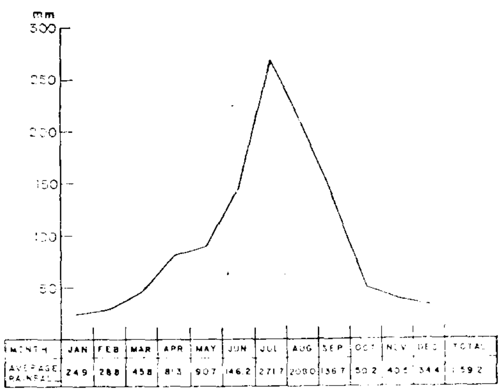

Figure 3. Variation of Mean Monthly Rainfall

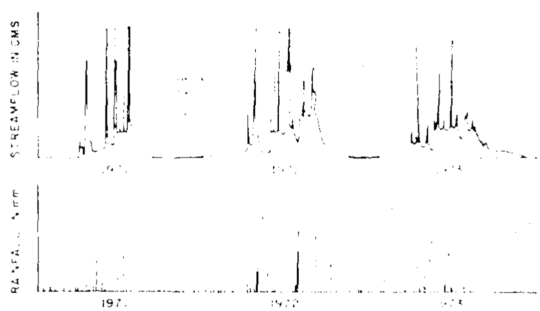

Figure 4. Variation Pattern of Daily Streamflow and Rainfall in Seoul

The systematic variation pattern of water resources in the long term period can be expressed by the relationship between annual average and standard deviation of river runoff. Therefore, this relationship is described as the following mathematical model from the research results of Markovic (1965) and Waitt and O'Neill (1969) and the fitness of annual runoff in Korea to log-normal distribution (Lee and Cho, 1974):

$$\sigma = ae^{-bL} \qquad \cdots\cdots(2)$$

where σ is stanard deviation; $L=\log_{10}Q$ is average value of logarithm of annual runoff (Q); a and b are regression coefficients which indicate regional characteristics. This equation means the simplification of complex regional factors by a variable of average annual runoff to show the systematic variation pattern of water resources.

Under the above assumption, annual runoff data in Korean rivers were analyzedand the following relationships were obtained (Lee, et al., 1976):

$$\left.\begin{array}{l}\sigma=0.995e^{-0.5607L}, \text{ for Nakdong River} \\ \sigma=0.2463e^{-0.0267L}, \text{ for Korean Rivers}\end{array}\right\} \qquad \cdots\cdots(3)$$

Analyzed data and above equations are shown in Figure 5. (a) and 5(b) with some ther countries data. It can be seen from these figures that L and σ values in Korean rivers range from 2.6 to 3.6 and from 0.2 to 0.4, respectively, whereas those values of other continental areas range from quite low values to high values widely. This means that the variability of annual run off in Korea is relatively smaller than other continents in the world even though there exist severe seasonal fluctuations.

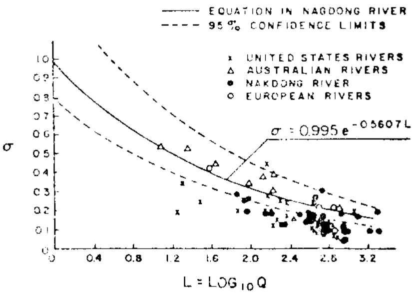

Figure 5(a) Variability of Annual Runoff in Nakdong River

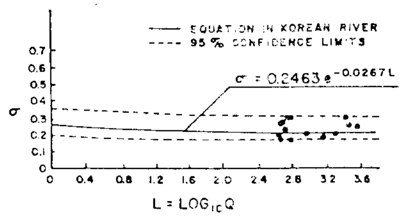

Figure 5(b) Variability of Annual Runoff in Korean Rivers

These variation patterns are also related with the stochastic characteristics of hydrological variates closely. Correlogram and spectrum analyses were made to find some stochastic characteristics from annual, monthly and daily rainfall and streamflow sequences, and some of the typical correlograms and power spectral diagrams are shown in Figure 6. and 7 (Lee, 1975; Lee, et al. 1976; Lee, 1979; Lee and Um,

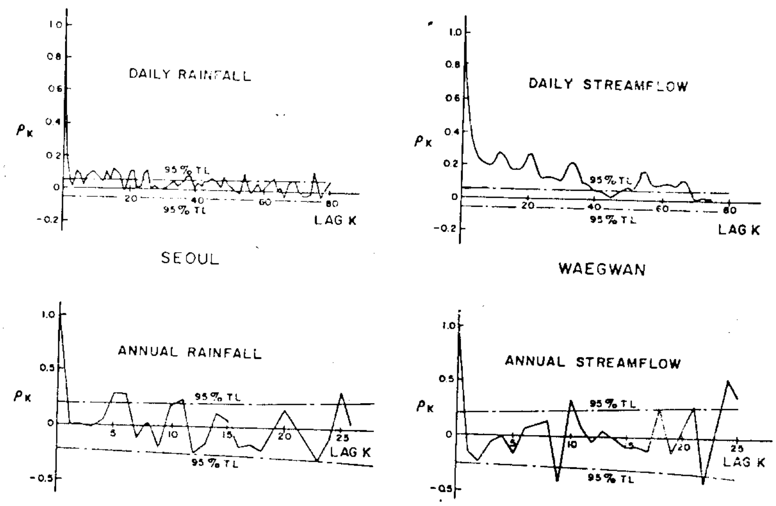

Figure 6. Correlogram of Historical Daily and Annual Rainfall and Streamflow

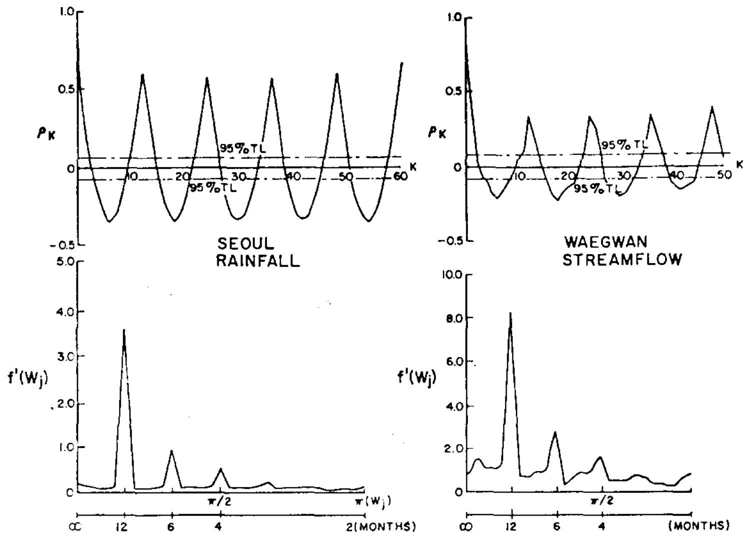

Figure 7. Correlogram and Spectrum of Histrical Monthly Rainfall and Streamflow

1979). Correlograms of daily and annual rainfall and streamflow are oscillating without revealing any presence of harmonic components. But the harmonic components with 365-day periodicities were generally found in the correlograms of daily rainfall and streamflow with long lag. On the other hand, all correlograms of monthly rainfall and streamflow are also oscillating without any indication of damping, thus revealing the presence of harmonic components with 12-month periodicities in the processes. These harmonic components in monthly hydrologic processes become more clear in the power spectrum. The sharp peaks exhibited in these spectra indicate a significant amount of the variance with 12-month and 6-month periodicities.

It was also found that most of these hydrologic processes became the stationary time series by the first standardization, and the best fit probability distribution function was 2-parameter gamma function in most hydrologic processes.

Water Demand-Supply Relationship

Projection of Water Demand-Supply

The measurement of use of water by sectors and the projection of water demand in Korea was made from the estimation of present and future consumptive use and losses of water for municipal and domestic, manufacturing, agricultural and other purposes.

The population growth in each basin was estimated from the total population growth for the estimation of domestic and municipal water use. In most of the five water management areas in Korea, the projection was made by dividing the area into several subregions according to the concurrent population or the prospect of economic growth.

The area of arable and irrigable land was then estimated in order to make the projection of future water demand for agriculture. The demand for live stock and poultry has also been investigated to know its water use

Thus, in order to make a projection of future industrial water demand, the future industrial production for various types of manufactures was estimated. But comprehensive projection was not possible throughout the nation due to information available.

Finally, the water use for mining, steam and hydropower generation, and inland navigation and fishery were estimated on national basis from available data.

After the estimation of water use by sectors, total water withdrawn from stream per unit was estimated to get the water consumption for each sector. First of all, water use per capita was estimated according to the type of area, i.e. urban and rural area in each basin with the consideration of the growth of population and projected water consumption per capita for domestic and municipal life.

Nextly, unit water consumption for irrigation and agriculture was estimated from the required water per unit area and crops. In this estimation, effective rainfall, soil moisture and infiltration, evapotranspiration and other all related factors were introduced and total water consumption per hectare was estimated for both arable and irrigable area. Then, total water withdrawn from stream per unit manufacturing production was estimated from the total production and unit water requirement for each product. As a result, total water consumption and demand for each sector were estimated as shown in Table-2. It is expected at the end of year 2001 that the consumptive use and water losses may increase from 11 billion metric tons to 35 billion tons.

Annual mean flow volumes and annual streamflow volumes equalled or exceeded the percent of time were then estimated from the annual average rainfalls, loss rates and annual flow duration curves in each basin. The results are shown in Table-3, and these streamflow volumes are the dependable water supply for future demand in Korea. Therefore, these dependable water supply values are compared with above estimated total water consumption in each basin as well as the whole country in Table-4. It can be seen from this Table that water demand in most of the river basins and the whole country can be met by the dependable water supply for only 50% of the time at the present time and for less than 50% of the time from 1986. This means that water resources conservation and its effective management are urgently needed to meet the present and future water demand.

Table-2. Estimated Consumptive Use and Losses of Water in Korea (As Volume of 10^6m^3 and Percentage of Total Withdrawal)

Type Unit Year	Domestic & Municipal		Manufacturing		Agriculture		Others		Total	
	10^6m^3	%	10^6m^3	%	10^6m^3	%	10^6m^3	%	10^6m^3	%
1971	939	8.4	969	8.7	6,235	56.0	2,983	26.9	11,126	100
1976	1,441	10.5	2,036	14.8	7,219	52.8	2,983	21.9	13,679	100
1981	2,059	11.7	3,704	21.6	8,456	49.4	2,983	17.3	17,303	100
1986	2,767	13.1	5,896	27.9	9,456	44.9	2,983	14.1	21,102	100
1991	3,548	14.1	8,267	32.9	10,264	41.1	2,983	11.9	25,062	100
1996	4,393	14.8	11,561	38.9	10,794	36.3	2,983	10.0	29,731	100
2001	5,373	15	16,193	45.3	11,214	31.3	2,983	8.4	35,763	100

Water Resources Development

As mentioned in the water demand-supply relationship, present and future water demand can not be met by the dependable water supply resourcesfully. Therefore, Korean government has been putting steady efforts to develop the water resources effectively through intensive river basin surveys and development programs and construction of multi-purpose dams from long time ago. Present status of dam construction is shown in Table-5 as one of the examples of water resources development activities in Korea. Referring to the present water supply forecasting, water intake from the rivers will run 17% in 1976 to slightly over 18% in 1981 of the total surface runoff, while shortage will remain at 10% in 1976, 26% in 1981,

Table-3. Dependable Water Supply for Future Demand in Korea.

River Basin	Drainage Area (km²)	Annual Mean Flow (m³/sec)	Annual Mean-Flow Volume (10⁶m³)	Annual Streamflow Volume Equalled or Exceeded the Percent of Time Indicated (10⁶m³) 50%	55%	60%	65%	70%	75%	80%	85%	90%
Han	26,219	573	18,060	5,992	5,345	4,762	4,352	3,879	3,564	3,185	2,838	2,428
Nakdong	23,656	476	15,000	5,077	4,447	4,005	3,532	3,185	2,901	2,618	2,334	2,018
Geum	9,887	203	6,000	2,145	1,892	1,703	1,482	1,388	1,261	1,132	1,003	877
Yeungsan	2,797	56	1,770	590	520	470	416	378	344	312	281	246
Remaining Basin	35,918	690	22,170	7,253	6,370	5,708	5,203	4,699	4,163	3,784	3,311	2,949
Whole Country	98,477	1,998	63,000	21,057	18,574	16,648	14,985	13,529	12,233	11,031	9,767	8,518

Table-4. Estimated Total Water Consumption with Dependable Water Supply in Each Basin in Korea.

Year	Han		Nakdong		Geum		Yeungsan		Remaining		Whole Countr	
	Demand	Supply (%)*	Demand	Supply (%)	Demand	Supply (%)	Demand	Supply (%)	Demand	Supply (%)	Demand	Supply (%)
1971	3,015	80%	3,296	65%	1,582	60%	755	<50%	2,478	90%	11,126	76%
1976	4,019	65%	3,880	60%	1,917	50%	911	<50%	2,952	85%	13,679	65%
1981	5,364	50%	4,566	50%	2,642	<50%	1,213	<50%	3,417	80%	17,202	55%
1986	7,071	<50%	5,205	<50%	3,252	<50%	1,469	<50%	4,105	75%	21,102	<50%
1991	9,374	<50%	5,703	<50%	3,743	<50%	1,701	<50%	4,521	70%	25,062	<50%
1996	12,510	<50%	6,003	<50%	4,009	<50%	1,900	<50%	5,309	60%	29,731	<50%
2001	16,833	<50%	6,313	<50%	4,214	<50%	2,057	<50%	6,346	55%	35,763	<50%

* Percentage level in whichd ependable water supply is equalled or exceeded the demand of the percent of time.

and 33% in 1986. It follows that the current pace of water sesources development in the form of estuary barrages and dams will continue to fall far short of meeting water demand both current and projected.

As the nation's hydrological characteristics rule out stable water intake from the rivers, water projects in Korea are concentrated on theyear-round stabilization of river runoff, both by such conventional means as multi-purpose dams, barrages, runoff control and extended utilization of reservoirs for a greater utility of water, and by such radical modes as the rehabilitation of river basins via multi-purpose channels along an extensive development scheme to minimize the regional gaps in water resources.

From the community water supply points of view, Korea has higher percentages of water supply than average value of 14 UN/ESCAP countries according to the World Health Organization (WHO)'s estimation. That is, rural population with reasonable access to community water supply averaged 34% in 1970 and urban population served averaged 88%, which were greatly improved since then.

With the national development of water resources in the surface water as well as groundwater, water quality and pollution control were also carried out through the legislation to protect the river water quality and the construction of sewage and waste water treatment plants.

Hence, Korea is continuing its efforts to remedy the projected future shortage of water by utilizing all the water facilities developed during earlier eras, plus those new dams and barrages either completed, under construction or on blue prints as part of the on-going development program.

Table-5. Existing Dams and Planned Dams

River System	Class	Name of Dam	Dam Type	Data for Dam: Height (m)	Data for Dam: Length (m)	Data for Dam: Volume (m³)	Gross Storage (Million m³)	Active Storage (Million m³)	Conservation Water Level (EL. m)	Reservoir Area (km²)	Benefit: Flood Control (Mil, m³)	Benefit: Water Supply (Mil. m³)	Benefit: Power Generation (kW)
Han River	Existing	Hwachon	Concrete Gravity	78	435	800,000	1,018	658	181	38.9	215		108,000
	Existing	Chunchon	〃	40	453	250,000	150	61	103	14.32			57,600
	Existing	Yuam	Concrete Weir	23	224	36,000	80	39	71.5	17.2			45,000
	Existing	Chungpyong	Concrete Gravity	31	407	234,000	185	83	51	17			79,600
	Existing	Goysan	〃	28	171	50,000	15	6	135.65	6.71			2,600
	Existing	Soyang	Rockfill	123	530	9,592,200	2,900	1,900	193.5	70	500	1,213	200,000
	Existing	Paldang	Concrete Weir	29	510	250,000	244	180	25.50	36.5			80,000
	Planned	Imgye	Rockfill	75	290	1,531,000	265	218	525	10.9	9	274	153,000 (1,000,000)
	Under Construction	Chungju	Concrete Gravity	88.5	450	731,000	3,080	1,880	142.2	101.4	600	2,002	210,000

Table-5. (Contd.)

River System	Class	Name of Dam	Dam Type	Data for Dam Height (m)	Length (m)	Volume (m^3)	Gross Storage (Million m^3)	Active Storage (Million m^3)	Conservation Water Level (El. m)	Reservoir Area	Benefit Flood Control (Mil, m^3)	Water Supply (Mil, m^3)	Power Generation (kW)
Nakdong River	Existing	Namgang	Earth	21	975	825,000	136	108	37.5	23.65	43 (860)	77	12,600
	Existing	Andong	Rockfill	73	525	4,042,000	1,230	1,000	160	51.5	110	926	90,000
	Existing	Youngchun	Rockfill	55	340	1,419,000	216	139	165	8.1	15	80	
	Planned	Habchun	Rockfill	93	482	4,004,000	794	543	176	27.6	72	524	80,000
	Planned	Daechung	Rockfill	45		1,150,000	123	106	150.5	7.4		124	
Geum River	Under construction	Daechung	Rockfill Gravity	58	495	1,178,000	1,490	1,040	76.5	72.8	250	1,649	90,000
Sumjin River	Existing	Bosung	Concrete Gravity	12	904	42,000	5	4.7	127.27	1.8			3,120
	Existing	Sumjin	Concrete Gravity	64	344	410,000	466	370	196.5	26.5	27	150	8,800
Yeungsan River	Existing	Changsung	Earth	36	613	1,189,000	89.7	84.8	86.5	5.6	6.0	96	
	Existing	Damyang	Earth	46	316	1,681,000	66.7	64.8	119.5	2.2	4.0	53.2	
	Existing	Daecho	Earth	31	496	1,170,000	91.2	87.8	63.9	6.3	6.5	72.6	
	Existing	Dongbok	Earth	46	202	498,700	126	91.7	170.0	7.6	15	92	3,000

Conclusions

Variation pattern and stochastic characteristics and projected demandsupply relationship of water resources in Korea with its present progress of development were discussed in this paper. The systematic variation pattern of water resources was expressed by the exponential relationship between annual average and standard deviation of river runoff, from which the variability of annual runoff in Korea was found to be relatively smaller than other continents in the world even though there exist severe seasonal variations. And, any presence of harmonic components was not shown from the correlogram and spectrum analyses of daily and annual rainfall and streamflow sequences whereas correlograms and power spectral diagrams of monthly rainfall and streamflow revealed the presence of harmonic components with 12-moth and 6-month periodicities in the monthly hydrological processes. Then, it was found from the comparison of projected total water consumption with dependable water supply that water demand in most of the river basins in Korea can be met by the dependable water supply for only 50% of time period at the present time and for less than 50% of time period from 1986. This shortage of dependable water supply was discussed in the present progress of water resources development in Korea.

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