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マイクロ作成

MINISTRY OF CONSTRUCTION
GOVERNMENT OF THE REPUBLIC OF KOREA

PRELIMINARY FEASIBILITY REPORT ON THE LONG-TERM MULTIPURPOSE DAM SCHEMES

(SECOND STAGE)

VOL. 1

MAIN REPORT

SEPTEMBER 1979

JAPAN INTERNATIONAL COOPERATION AGENCY

PREFACE

Following the request of the Government of the Republic of Korea to the Government of Japan, the Japan International Cooperation Agency (JICA), the executing agency of the Government of Japan for the overseas technical cooperation program, has carried out a Preliminary Feasibility Study on the Long-Term Multipurpose Dam Schemes in two stages.

The first stage of the Study was conducted between October, 1977 and June, 1978. The second stage of the Study was made from July, 1978 to September, 1979, for the purpose of preliminary feasibility study on the multipurpose development of 10 dams which were selected as a result of the first stage of the Study. The survey team headed by Mr. Ichiro Kuno carried out the field survey from July, 1978 to March, 1979.

The JICA established an advisory committee headed by Mr. Nobuo Aihara and comprising the officials of the Ministry of Agriculture, Forestry and Fisheries, Ministry of International Trade and Industry, Ministry of Construction, Government of Fukuoka Prefecture, and Water Resources Development Public Corporation of Japan to give advice to the survey team throughout the study period. The Ministry of Construction, Ministry of Agriculture and Fisheries and other authorities concerned of the Republic of Korea extended close cooperation to the survey team.

The presented report has been formulated as a result of the above two-staged studies and consultations with the officials concerned of the Korean Government. I hope the report will prove to be useful for the water resources development and contribute to the social and economic development of the Republic of Korea.

I wish to express my heartfelt appreciation to the Government and officials concerned of the Republic of Korea for their kind cooperation extended to the survey team.

September, 1979

Shinsaku Hogen
President
Japan International Cooperation Agency

September, 1979
Tokyo

Mr. Shinsaku Hogen
President
Japan International
Cooperation Agency
Tokyo

Dear Sir,

LETTER OF TRANSMITTAL

We are pleased to submit to you the Final Report of the Long-Term Multipurpose Dam Schemes Preliminary Feasibility Study - Second Stage - prepared for consideration by the Government of the Republic of Korea in planning the long-term multipurpose water resources development. Fully incorporated in the Report are the advice and suggestions of the Advisory Committee set up by your Agency specifically for the Study, as well as the comments made by the Government of the Republic of Korea.

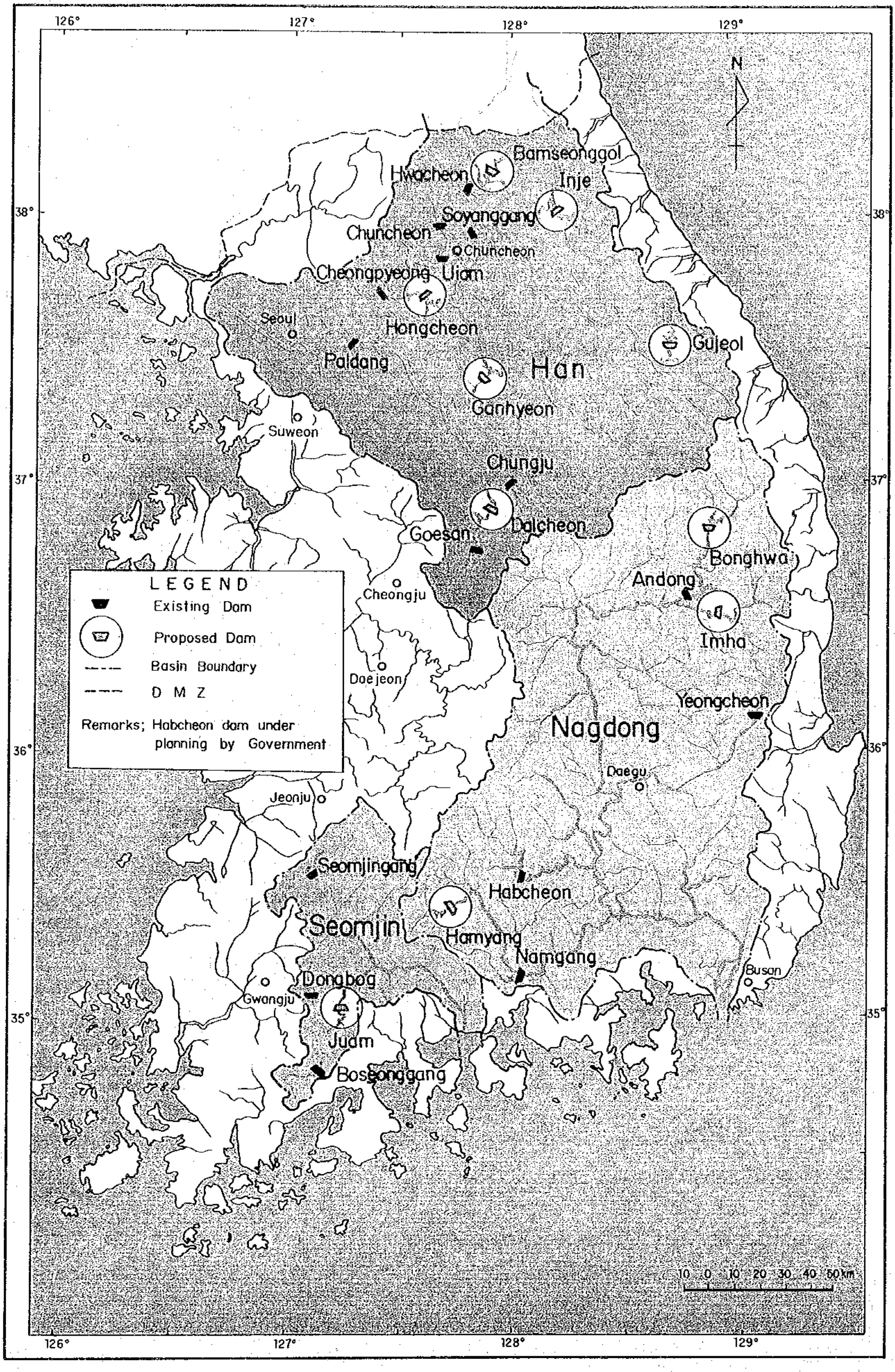
Among the proposed 10 dams, the Bamseonggol, Hongcheon, Dalcheon and Ganhyeon dams in the Han river, the Imha dam in the Nagdong river and the Juam dam in the Seomjin river, if constructed, will greatly contribute to the basin's water resources development showing a high economic viability. The proposed Inje, Gujeol, Bonghwa and Hamyang dams, appeared to be less economical, but could be considered, if social needs so dictate.

Because of the basin-wide influence by the multipurpose dams, the Report presents important results to be taken into account in planning not only dams but any kind of water resources development. Up-to-date projections were made for the municipal and industrial water demand and agricultural land development. The water budgets prepared for the Han, Nagdong and Seomjin river basins are without doubt the basic tools for planning the integrated basin's development. The flood damage was evaluated in relation with the river hydrology. Land enhancement benefit by flood control was also estimated. A maximum utilization of power potential has been indicated.

Grateful acknowledgement is made to the personnel of your Agency, the Advisory Committee, the Embassy of Japan in Seoul, the Ministry of Foreign Affairs, the Ministry of Agriculture, Forestry and Fisheries, the Ministry of International Trade and Industry, the Ministry of Construction and the Water Resources Development Public Corporation of Japan. We also wish to express our sincere gratitude to the officials of the Ministry of Construction, Ministry of Agriculture and Fisheries and other authorities and agencies concerned of the Republic of Korea for their close cooperation, assistance and advice extended to us during our field survey.

Very truly yours,

Ichiro Kuno
Team Leader
Long-Term Multipurpose
Dam Schemes Preliminary
Feasibility Study Second Stage



LEGEND
Existing Dam
Proposed Dam
Basin Boundary
D M Z
Remarks; Habcheon dam under planning by Government
Bamseonggol
Hwacheon
Inje
Soyanggang
Chuncheon
Chuncheon
Cheongpyeong
Uiam
Hongcheon
Seoul
Paldang
Gujeol
Han
Ganhyeon
Suweon
Chungju
Dalcheon
Goesan
Bonghwa
Andong
Cheongju
Imha
Daejeon
Yeongcheon
Nagdong
Daegu
Jeonju
Seomjingang
Habcheon
Seomjin
Hamyang
Namgang
Busan
Dongbog
Gwangju
Juam
Bosenggang
126°
127°
128°
129°
38°
37°
36°
35°
N
10 0 10 20 30 40 50km

LIST OF VOLUMES

Remarks; Volume 1 is submitted in September, 1979, while Volumes 2 to 5 were submitted in July, 1979.

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GLOSSARY

Local Terms of Administrative Areas

Do	-	Province
Gun	-	Subdivision of province, similar to a county
Myeon	-	Subdivision of a Gun
Ri	-	Village of community of more than one village
Eub	-	Town of the administrative level of a Myeon
Si	-	City of the administrative level of a Gun
Si	-	Special City of the administrative level of a Do
Gu	-	Subdivision of special city equivalent to Gun
Dong	-	Subdivision of Gu or Si equivalent to Myeon or Eub
Sa	-	Temple

Natural Features

San	-	Mountain
Cheon	-	Small river
Gang	-	Larger river
Do	-	Island
Bug	-	North
Dong	-	East
Nam	-	South
Seo	-	West

Spelling of names of places, rivers, etc.

The forms of English spelling of the regions, rivers, etc. that have been adopted are those promulgated by the National Ministry of Education.

CONVERSION FACTORS AND ABBREVIATIONS

1) Length

mm = millimetre
cm = centimetre
m = metre
km = kilometre

2) Areas

ha = 10^4 m^2 = hectare
Pyeong = 3.31 m^2
danbo = 300 pyeong = 992 m^2
Jeongbo = 100 danbo = 0.992 ha

3) Volume

lit = 1,000 cm^3 = litre
Seok = Volume containing
100 kg unhulled rice
144 kg polished rice
105 kg barley
138 kg naked barley
141 kg polished barley
138 kg wheat
114 kg unhulled millet
124 kg polished millet
142 kg rye
135 kg corn
135 kg soybeans

4) Weight

mg = milligramme
g = gramme
kg = kilogramme
ton = 1,000 kg = ton
gwan = 3.75 kg
geun = 0.16 gwan = 600 g

5) Time

s = second
min = minute
h = hour
d = day
yr = year

6) Money

$ = US dollar
₩ = Won
$ = ₩ 485, 1978 price level
mill = $ 10^{-3}

7) Electrical Measures

V = Volt
A = Ampere
H = Hertz (cycle)
kV = Kilovolt
W = Watt
kW = Kilowatt
MW = Megawatt
kWh = Kilowatt hour
MWh = Megawatt hour
GWh = Gigawatt hour
ohm = Resistances
mho = Micromhos = Conductance

8) Other Measures

ppm = parts per million
% = per cent
o/oo = per thousand
PS = Horse power (75 mkg/s)
pH = scale for acidity
°C = degree centigrade
10^3 = thousand
10^6 = million
10^9 = billion (milliard)

9) Derived measures are based on the same symbols:

m^3/s = cubic metre per second
ton/ha = ton per hectare
kWh/yr = kilowatt hour per year
kVA = kilovolt ampere

10) Technical Terms

BOD = Biochemical oxygen demand
dia. = Diametre
El. = Elevation above mean sea level
H = Height or water head
HWS = Reservoir high water surface
K = Potassium
LWS = Reservoir low water surface
N = Nitrogen
P = Phosphorus
PVC = Polyvinyl chloride
TSP = Triple superphosphate
TWS = Tailwater surface of turbine

ABBREVIATIONS

ADB	Asian Development Bank
ADC	Agricultural Development Corporation
BOK	Bank of Korea
DMZ	Demilitarized Zone
EPB	Economic Planning Board
FAO	Food and Agriculture Organization of the United Nations
FLIA	Farm Land Improvement Association
HRBS	USAID/KOWACO Han River Basin Joint Survey Team
IBRD	International Bank for Reconstruction and Development
IR	International Rice Research Institute
ISWACO	Industrial Site and Water Resources Development Corporation
JICA	Japan International Cooperation Agency
KECO	Korea Electricity Company
KOWACO	Korea Water Resources Development Corporation, Previous name of ISWACO
MAF	Ministry of Agriculture and Fisheries
MOC	Ministry of Construction
NACF	National Agricultural Cooperatives Federation
OECF	Overseas Economic Corporation Fund, Japan
ORD	Office of Rural Development
PORD	Provincial Office of Rural Development
UNDP	United Nations Development Programme
UNSF	United Nations Special Fund
US/AID	United States Agency for International Development
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USCE	United States Corps of Engineers
KOR 13	UNDP/FAO Soil Survey Project
KOR 16	UNDP/FAO Pre-Investment Survey of the Nagdong River Basin Project
KOR 72	UNDP/FAO Nagdong River Basin Delta Study
KOR 75	UNDP/FAO Nagdong River Basin Development Project Feasibility Study

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

1. The Government of the Republic of Korea has implemented large multipurpose dams such as the Soyanggang, Andong, Daecheong and Chungju dams since the late 1960s. It is though foreseen that additional dams will be needed in the near future in view of the rapid industrialization, intensified land use and need for stable food supply.

2. Since agreed for such in 1977 between the Government of Japan and the Government of the Republic of Korea, a Long-Term Multipurpose Dam Schemes Preliminary Feasibility Study has been carried out by the Japan International Cooperation Agency (JICA) for the purpose of identification of future multipurpose dams from the viewpoint of integrated water resources development.

3. The first stage of the Study which ended in June, 1978 resulted in the selection of 10 dams from among 24 proposed dams. The selected dams are the Bamseonggol, Inje, Hongcheon, Gujeol, Dalcheon and Ganhyeon dams in the Han river basin, the Bonghwa, Imha and Hamyang dams in the Nagdong river basin and the Juam dam in the Seomjin river basin. A more detailed study has been carried out for these 10 dams in the second stage of the Study and the results of all the studies are presented in the Final Report.

4. Annual rice production in Korea has remarkably increased since the introduction of high-yielding varieties in 1972 and it attained a self-sufficient level of 6 x 10^6 tons in 1977. The agricultural land development in the future will be closely related to and dependent upon the development of irrigation for more stable food production and land consolidation for the mechanization, labor-saving and better water management. Pertinent figures relating to this are as follows:

Unit: 10^3 ha

	Han		Nagdong		Seomjin	
	1976	2001	1976	2001	1976	2001
All cultivated areas	338	342	478	473	98	100
All paddy	156	162	285	287	64	65
Irrigated paddy	102	135	206	258	39	52
Consolidated paddy	18	98	76	185	7	34
All upland areas	182	180	193	186	34	35
Irrigated upland areas	-	16	18	47	-	2

5. The municipal and industrial (M&I) water requirement in the Seoul-Incheon metropolitan area is the predominant one in the Han river basin. Most water for this area will be taken from the Paldang dam in the near future, upon the completion of the on-going construction of the Metropolitan Water Supply Project. Large M&I water demand centers in the Nagdong river basin include Daegu and Gumi, but even more water is taken from the Nagdong

river by adjacent coastal cities such as Busan, Ulsan, Pohang and Masan. The Seomjin river has been used for diverting M&I water to Gwangju city and the Honam Chemical Industrial Estate in Yeocheon. The industrial development on the Gangyang bay coast, including Yeocheon, will be accompanied by a large M&I water demand in the future. A study on the M&I water requirements in 116 municipalities and 21 industrial areas resulted in the following projection:

	Han		Nagdong		Seomjin	
	1976	2001	1976	2001	1976	2001
Urban population (10^6)	9.8	15.8	6.3	10.8	0.2	0.6
Municipal water demand (10^6 m^3/year)	777	2,238	333	1,429	18	86
Industrial water demand (10^6 m^3/year)	209	1,474	201	1,085	5	444
Total M&I (10^6 m^3/year)	986	3,712	534	2,514	23	530

6. A water budget analysis which takes into account M&I water demand, agricultural water demand and river maintenance flow showed that the water demand in the tributaries would tend to reduce available water in the main streams, where the water demand will be growing at a high rate. The water deficit will take place in the dry periods which often occur not only in the winter but also in the summer. It will be very high especially in the summer, during which time the irrigation water demand is large. Assuming that there is no outflow from the

Soyanggang dam and Chungju dam in the Han river basin and the Andong dam in the Nagdong river basin, the growth of the peak water deficit was calculated as follows;

	1986	1991	1996	2001
Han river (m^3/s)	71	85	104	132
Nagdong river (m^3/s)	143	159	169	179
Seomjin river (m^3/s)	13	17	19	22

7. The regulated outflow in the peak deficit period was estimated to be 55.5 m^3/s for the Soyanggang dam and 119.5 m^3/s for the Chungju dam, totalling 175 m^3/s which can meet the deficit in the Han river until 2008. The Andong dam can supply 142.5 m^3/s of peak deficit which corresponds to the 1985 water deficit in the Nagdong river. This implies that the preparation for the construction of a new dam should be started as soon as possible. The Government is planning to construct the Habcheon dam or an estuary barrage on the Nagdong river. The net deficit supply capacity was estimated to be 13.8 m^3/s for the Habcheon dam and 24.1 m^3/s or less for the barrage. It was assumed that the Habcheon dam rather than the barrage would be constructed as the next project after the Andong dam, because time would be needed for taking purification measures at Daegu and Gumi and some additional studies have to be made before the construction of the barrage can be started. Another dam after the Habcheon dam has been constructed will be

required as of 1990. It is estimated that there will be a water deficit during each dry year in the Seomjin river, even under the present water demand conditions.

8. The water supply capacity of the proposed dams was investigated and accordingly the target year of full supply was set, based on both a constant draft operation and variable draft operation. A constant draft operation is one in which the rate of the regulated outflow is kept constant throughout the year like in an ordinary power generation dam, while a variable draft operation is one in which the rate of the regulated outflow varies in accordance with the water deficit such as has been carried out by the Andong dam. The variable draft operation showed quite a significant advantage in the water supply capacity in the Han river, because of the short duration of the deficit periods after the Soyanggang and Chungju dams. The future dam will be assigned to a long lasting deficit in the Nagdong river where the Andong dam has already clipped off the peak deficit, but some advantage of the variable draft operation can still be expected. The advantage of the variable draft operation for the Han river also applies to the Seomjin river water supply. The variable draft operation maximizes the net water supply capacity, while the constant draft operation maximizes the power generation. There will be an intermediate method (semi-variable draft operation) to favor both the water supply and power

generation by releasing outflow at an appropriately high rate in the non-deficit periods and augmenting it in the peak deficit period.

9. The constant draft operation was studied for the proposed dams of which water head allows power generation. The variable draft operation was also considered for the proposed dams unless such operation is ineffective due to downstream large reservoir. For the proposed Juam dam in the Seomjin river, the main stream plan and diversion plan were investigated. In the main stream plan, the dam releases the regulated outflow immediately downstream for the intake from the Seomjin river by the water users. The diversion plan envisages to divert most water in the proposed reservoir to the demand centers through a diversion tunnel and pipelines which will be placed across the southern coast adjacent to the Seomjin river basin. Three alternative routes of diversion system were investigated. Route A is the shortest course connecting the proposed reservoir and the Gwangyang bay coast which was assumed to be the demand center. Route B includes the construction of a dam in the southern coast. Route C passes presumable irrigation water demand centers on the way.

10. The proposed dam schemes were envisaged for the purposes of M&I water supply, agricultural water supply, flood

control and power generation. The M&I water supply benefit was estimated based on the cost of the least-costly alternative dams, of which the estimated cost of water ranged between 9 mills/m^3 and 39 mills/m^3 at a discount rate of 8 %. The agricultural water supply benefit building up between the year of commission and the full supply target year was estimated as the net production value less the cost of irrigation facilities. The flood control benefit was estimated based on the historical damage which occurred in 1967-1976. Counted benefits were the direct flood damage reduction and land enhancement benefit which would arise from more beneficial cropping under less frequent flooding of the land. The power generation benefit was based on the cost of an alternative thermal power plant. Its annual equivalent is a composition of the capacity value of $ 68.73/kW and the energy value of 22.87 mills/kWh at a discount rate of 8 %. To be consistent with the other benefits and costs, the energy value was estimated based on the price of Bunker C fuel oil of ₩ 46/lit (95 mills/lit) which is the ex-factory price in July, 1978. The case in which the above-mentioned price is doubled was also studied, taking into account the fact that the oil price is rising high recently. The production which must be foregone as a result of the proposed reservoir was estimated as a loss in the net agricultural production value.

11. An economic optimization of the proposed dams was made based on the net benefit maximization criteria in which the benefits less the costs (B - C) should be maximized. All the estimated benefits and costs were converted into the annual equivalents assuming a discount rate of 8 %, which has been regarded as the minimum acceptable for water resources development in Korea. As a result, 12 schemes made up of six proposed dams were justified and optimized, but four dams were found to be less economical. An outline of the dam schemes are summarized in the following tables.

JUSTIFIED DAM SCHEMES

Name of Dam		Bamseonggol	Hongcheon	Hongcheon
River system		North Han	North Han	North Han
Operation method		Constant draft	Constant draft	Variable draft
High water surface	(El. m)	305	120	120
Active storage capacity	(10^6 m^3)	368	954	954
Dam height	(m)	105	80	80
Net water supply capacity	(m^3/s)	10.0	18.1	93.0
Installed capacity	(MW)	50	73	-
Investment cost	(\$ 10^6)	125	169	136
Year of commission		2008	2008	2008
Full supply target year		2010	2011	2025
Economic benefit	(\$ 10^6)	12.03	13.57	22.95
Economic cost	(\$ 10^6)	11.43	12.42	8.22
B - C	(\$ 10^6)	0.60	1.15	14.03
B/C ratio		1.1	1.1	2.8
Economic internal rate of return	(%)	8.5	8.8	14.8
B/C ratio if energy value doubled		1.4	1.4	2.9

JUSTIFIED DAM SCHEMES

Name of Dam		Dalcheon	Ganhyeon	Imha
River system		South Han	South Han	Nagdong
Operation method		Variable draft	Variable draft	Constant draft
High water surface	(El. m)	117	111.4	192
Active storage capacity	(10^6 m^3)	540	540	920
Dam height	(m)	57	50	87
Net water supply capacity	(m^3/s)	81.3	79.7	15.6
Installed capacity	(MW)	-	-	48
Investment cost	(\$ 10^6)	150	95	155
Year of commission		2008	2008	1990
Full supply target year		2023	2022	1997
Economic benefit	(\$ 10^6)	17.47	18.20	13.01
Economic cost	(\$ 10^6)	5.75	3.52	11.82
B - C	(\$ 10^6)	11.72	14.68	1.19
B/C ratio		3.0	5.2	1.1
Economic internal rate of return	(%)	15.3	20.2	8.8
B/C ratio if energy value doubled		3.1	5.2	1.3

JUSTIFIED DAM SCHEMES

Name of Dam		Imha	Juam Main Stream	Juam Main Stream
River system		Nagdong	Seomjin	Seomjin
Operation method		Variable draft	Constant draft	Variable draft
High water surface	(El. m)	185	120	111
Active storage capacity	(10^6 m^3)	583	780	448
Dam height	(m)	81	69	60
Net water supply capacity	(m^3/s)	22.0	17.7	27.2
Installed capacity	(MW)	-	8	-
Investment cost	(\$ 10^6)	113	169	126
Year of commission		1990	1986	1986
Full supply target year		2000	1993	2009
Economic benefit	(\$ 10^6)	9.78	13.32	17.81
Economic cost	(\$ 10^6)	7.55	9.58	7.61
B - C	(\$ 10^6)	2.23	3.74	10.20
B/C ratio		1.3	1.4	2.3
Economic internal rate of return	(%)	9.8	10.8	14.5
B/C ratio if energy value doubled		-	1.5	-

JUSTIFIED DAM SCHEMES

Name of Dam		Juam Dam Diversion Plan Route A	Route B	Route C
River system		Seomjin	Seomjin	Seomjin
Operation method		Variable draft	Variable draft	Variable draft
High water surface	(El. m)	120	114	120
Active storage capacity	(10^6 m^3)	780	530	780
Dam height	(m)	69	62	69
Net water supply capacity	(m^3/s)	24.4	21.2	24.4
Installed capacity	(MW)	-	-	-
Investment cost	($ 10^6)	146	133	146
Year of commission		1986	1986	1986
Full supply target year		2005	1999	2005
Economic benefit	($ 10^6)	16.82	13.12	12.25
Economic cost	($ 10^6)	8.75	8.01	8.75
B - C	($ 10^6)	8.07	5.11	3.50
B/C ratio		1.9	1.6	1.4
Economic internal rate of return	(%)	12.8	12.5	10.3
B/C ratio if energy value doubled		-	-	-

LESS ECONOMICAL DAM SCHEMES

Name of Dam		Inje	Gujeol	Bonghwa	Hamyang
River system		North Han	South Han	Nagdong	Nagdong
Operation method		Constant draft	Constant draft	Constant draft	Constant draft
High water surface	(El. m)	315	747	267	392
Active storage capacity	(10^6 m^3)	376	67	269	251
Dam height	(m)	98	66	97	94
Net water supply capacity	(m^3/s)	1.6	-	1.4	4.6
Installed capacity	(MW)	75	46	40	13
Investment cost	($ 10^6)	156	73	106	101
Year of commission		2008	1986	1990	1990
Full supply target year		2009	1986	1990	1991
Economic benefit	($ 10^6)	9.33	5.40	5.67	6.51
Economic cost	($ 10^6)	15.34	7.44	9.90	10.05
B - C	($ 10^6)	-6.01	-2.04	-4.23	-3.56
B/C ratio		0.6	0.7	0.6	0.6
B/C ratio if energy value doubled		0.9	1.0	0.8	0.9

12. The dams which were economically justified in the Han river were the Bamseonggol dam under the constant draft operation, the Hongcheon dam under both the constant and variable draft operations, and the Dalcheon and Ganhyeon dams both under the variable draft operation. The variable draft operation usually showed a great effect on the water supply and a high economic viability. On the other hand, the constant draft operation, though with rather low economic viability, could develop power potential to the maximum extent. These results suggest that after the completion of the Chungju dam, the Hongcheon, Dalcheon or Ganhyeon dam should be constructed next in order to meet the peak water deficit. The Hongcheon dam will probably be taken up, because it can not only serve for the water supply purposes but will be able to develop presumably a large power potential, if semi-variable operation or some other measure is introduced in favor of power generation.

13. The Imha dam in the Nagdong river was justified for both a constant draft operation and variable draft operation. This dam should be constructed with power facilities to be flexible enough for both the water supply and power generation.

14. Only the Juam dam is feasible as a large storage project in the Seomjin river basin, so far as the present study indicates. The dam will be required mainly for M&I

water supply to the southern coast adjacent to the Seomjin river basin. All the studied plans were justified. Among them, the main stream plan under the variable draft operation showed the highest economic viability. This plan should be taken up so far as the major water demand center is located on the Gangyang bay coast as assumed herein. The power potential, though it is minor, should be developed by introducing the semi-variable draft operation or some other means if the main stream plan is implemented. It is presumed that the diversion plan will be more important than the main stream plan, if the M&I and irrigation demand can be expected to increase in the area west of the Gwangyang bay, or if the water pollution in the estuary becomes a problem.

15. The Inje, Bonghwa, Gujeol and Hamyang dams could not be justified because they would contribute little to the basin's water supply; however, these dams could be taken up, if hydropower production becomes more important in the future. In fact, it was found that the Gujeol dam could be justified, if the fuel price for the thermal power is doubled relative to other prices.

16. The available hydrological data were not always sufficient during the course of the study. Therefore, intensified hydrological observation, especially flow

measurement at key stations and the establishment of gauging stations near the promising damsites are recommendable for more detailed study.

17. The present study is supported by the past estimates of the river maintenance flow which vary in regard to the depth of previous studies made for various basins. In this connection, attention is called to the survey and analysis of the water pollution and sea water intrusion in the lower Han river. The future requirement for the river maintenance flow might be much larger than the assumed, thereby requiring construction of a dam earlier than estimated.

18. Power generation was not assumed for the variable draft operation in the present preliminary feasibility study. It is recommended that, in the future stages, a semi-variable draft operation, running power generation or pumped-storage power generation of the Andong type be studied in relation with the variable draft operation.

1 INTRODUCTION

1.1 The Preliminary Feasibility Study

The Long-Term Multipurpose Dam Schemes Preliminary Feasibility Study has been carried out based on the Scope of Work agreed in the exchange of notes made between the Government of Japan and the Government of Republic of Korea in 1977. The Japan International Cooperation Agency (JICA), the executing agency of the Government of Japan, entrusted the Study to Nippon Koei Co., Ltd. cooperated with Electric Power Development Co., Ltd. The executing agency of the Government of Republic of Korea is the Ministry of Construction (MOC).

1.2 The First Stage of the Study

The Preliminary Feasibility Study has been executed in two stages. The first stage was carried out between October, 1977 and June, 1978 resulting in selection of 10 multipurpose dam schemes among 21 dam schemes proposed in MOC/ISWACO Hydroelectric Potential Survey in 1973 and three dam schemes recommended by USAID Han River Basin Survey (HRBS) in 1971.

The selected schemes were the Bamseonggol, Inje, Hongcheon, Gujeol, Dalcheon and Ganhyeon in the Han river basin, Bonghwa, Imha and Hamyang in the Nagdong river basin and Juam in the Seomjin river basin, their locations being shown in Fig. 1.

1.3 The Second Stage of the Study

The objective of the second stage was a preliminary feasibility study of the selected 10 dam schemes including (1) topographic and geological survey of proposed damsites, (2) study on the flood control and water supply effects of the proposed dams, (3) pre-feasibility design of proposed dam schemes, (4) optimization of the proposed dam schemes as the multipurpose dams, (5) estimate of investment cost of the proposed dam schemes and (6) estimate of benefit expected from the proposed dam schemes.

The field survey of the second stage was carried out between July, 1978 and March, 1979. It involved the socio-economic survey, hydrological study, topographic and geological exploration at proposed damsites, construction material survey, flood damage study, M&I water demand survey, agronomic study, agro-economic study, pedological study, irrigation development study and power market survey. Some works such as designing and computer analysis were carried out in Tokyo.

The field team of JICA were 24 in number as listed in Table 1. As the supporting service by MOC, counterparts worked in collaboration with JICA team and transportation and office space were provided. The work undertaken by Korean side was the topographic survey of the proposed damsites and other structural sites, geological drilling at the proposed damsites and compensation cost survey in the proposed reservoir areas. In addition to these supporting services, not only MOC but the Ministry of Agriculture and Fishery (MAF), Office of Rural Development (ORD), Industrial Sites and Water Resources Development Corporation (ISWACO), Agricultural Development Corporation (ADC), Korea Electric Company (KECO) and various authorities and agencies provided data and advices to JICA team.

In December, 1978, JICA team submitted a Progress Report which contained the progress of field work and major finding to date.

An Interim Report was submitted in March, 1979, describing the preliminary views and provisional conclusions so far reached by the end of the field survey. The outline of the 10 multipurpose dam schemes was provisionally set as shown in Tables 2 and 3.

The field results were further elaborated in Tokyo and a draft Final Report was submitted in July, 1979 for the review of the two Governments.

The second stage of the study was completed in September, 1979 by the submission of the Final Report which was prepared taking into account the comments made by the two Governments on the draft Final Report.

1.4 The Final Report

The Final Report describes the optimum scale, appropriate time of implementation, preliminary estimate of investment cost and economic viability of the proposed dam schemes in context of the long-term water resources development.

The supporting studies and basic data of the report were compiled in three volumes of ANNEXes and a volume of DRAWINGS which were submitted in July, 1979.

The Main Report in Volume 1 is attached with an ADDENDUM which contains additions and modifications of supporting studies prepared after the submission of the draft Final Report.

2 BACKGROUND

2.1 Land and Population

The Republic of Korea is located approximately between 33° and 39° north in latitude and between 124° and 131° east in longitude. The land of 98.8 x 10^3 km^2 consists of the southern half of the Korean peninsula and surrounding islands.

The climate is dominated by dry and cold continental air masses in winter and humid and warm air masses from the Pacific Ocean in summer. Rainfall is 1,200 mm per annum on an average and it mostly occurs in July and August.

The geological map of Korea is shown in Fig. 2. The tectonic zones of Korea are trending in northeast-southwest direction. The granite-gneiss system of the pre-Cambrian era is overlain by the marine and non-marine sedimentary rocks including limestone and coal seams of the Palaeozoic era in the upper south Han river basin and non-marine sedimentary rocks of late Mesozoic era (Cretaceous) in the greater part of the Nagdong river basin. There are wide belts and patches of granite intruded in the late Mesozoic era (Cretaceous). The Tertiary system is quite scarce.

Most mountains follow the direction of tectonic zones except the Taebaeg mountains along the east coast which is probably resulted from an asymmetric movement caused upheaval of the east coast. The east side of the Taebaeg mountains is steep toward the sea, while in the west side, the land slopes gently and the mountains lower toward the Yellow sea. Most rivers run toward the west, but the Nagdong and Seomjin rivers take general courses to the south. The river systems and mountains are shown in Fig. 3.

Korea is administratively divided into two Special Cities (Capital Seoul and Busan) and nine Does (provinces). The Does include 138 Guns (counties) and 34 Sis (cities). Guns are divided into Myeons (rural districts) and Eubs (urban districts), which are composed of Ris (villages).

According to 1975 population census, the national population was 34.71×10^6, or 351 persons/km^2. The growth rate between 1970 census and 1975 census is 2 % per annum. Table 4 shows population by Special Cities and Does in recent censuses. The migration trend to urban areas has been remarkable. The ratio of urban population to the national was 32 % in 1966, 40 % in 1970 and 47 % in 1975.

2.2 Economy of Korea

The annual growth rate of Korean economy was only 4 % in 1955-1961 and GNP was ₩ 297×10^9, or $ 87 per capita in 1961. The Government of Korea has executed four 5-year economic development plans since 1962. The fourth 5-year plan (1977-1981) is now on the way. The economy of Korea has remarkably developed owing to the export-oriented industrialization policy which has been maintained through the 5-year plans. According to a preliminary estimate by BOK in January, 1979, GNP in 1978 reached ₩ $22{,}256 \times 10^9$, or $ 1,242 per capita. This corresponds that the average annual growth rate was 10.2 % in real term after 1961.

The economic structure of Korea has largely changed by the fast industrial development. The share in GNP of the mining and manufacturing sector increased from 15.3 % to 28.2 % between 1961 and 1978, while the share of the agriculture, forestry and fishery sector decreased from 40.2 % to 21.2 % in the same period.

The commodity exports increased at a high average rate of nearly 40 % from $ 251×10^6 in 1966 and exceeded $ 10×10^9 in 1977. A preliminary estimate by BOK for 1978 was $ 12×10^9. The major export commodities are clothing, textile yarn and fabrics, electrical machinery, miscellaneous manufactured articles, footwear, iron and steel, transport equipment, and fish and fish product.

The commodity imports increased at an annual rate of 28 % from $ 716×10^6 in 1966 to $ $10{,}811 \times 10^6$ in 1977. Major commodities are petroleum products, machinery, transport equipment, chemical elements and compounds, cereals and cereal preparations, iron and steel, wood, lumber and cork, and textile fibres.

The import has usually exceeded the export reflecting the expanding need of raw materials and manufactured goods for industry. In consequence, the international balance of payment has remained in deficit. However, the deficit seems to have been decreasing recently.

The foreign exchange reserves increased from \$ 245 x 10^6 to \$ 4,306 x 10^6 between 1966 and 1977. The debt service ratio reached 18.7 % in 1971, but it has reduced to several percent in recent years.

The employed population was 12.9 x 10^6 in 1977. It increased at an average annual rate of 4 % during 1966-1977. In the same period, the weight of mining and manufacturing sector in the employed population changed from 11 % to 22 % and the weight of agriculture, forestry and fishery reduced from 58 % to 42 %.

Major economic data are shown in Table 5 and more details are described in ANNEX A.

2.3 Agriculture in Korea

The agricultural population in Korea was 12.3 x 10^6, or 34 % of the national population in 1977. The number of farm households were 2.34 x 10^6, corresponding to 5.3 persons per household. The average land holding size was 0.95 ha/household. Among the total farm households, 53 % held 0.5 to 1.5 ha and 34 % was the holders of less than 0.5 ha. It is estimated that 5.4 x 10^6 persons, or 42 % of the total employed population, were engaged in agriculture.

The cultivated area in Korea was 2.23 x 10^6 ha including 1.29 x 10^6 ha of paddy and 0.94 x 10^6 ha of upland in 1977. The principal crop is rice. Barley and wheat are cultivated as the second crops on paddy or the main crop on upland. Other annual crops are pulses, potatoes and vegetables. Mulberry field and orchard occupied 19 % of upland. The multiple crop index was about 140 % in 1977.

The economic disparity developed between the agricultural sector and non-agricultural sectors has caused a migration from the rural areas to the urban areas. The cultivated areas have been usually confronted by the infrastructural development and expansion of urban areas. The agricultural population reduced from 16.1×10^6 to 12.3×10^6, or from 53 % to 34 % of the national population, between 1967 and 1977. The cultivated area decreased from 2.31×10^6 ha to 2.24×10^6 ha in 1967-1977.

The agricultural production in Korea has been promoted by agricultural extension services and researches which are under the control of the Office of Rural Development (ORD) of the Government.

Tongil is a high-yielding new rice variety derived by crossing IR 8 to a hybrid of Yukara and Taichung Native 1 as a research result in the Crop Experiment Station of ORD at Suweon since 1967. It was put in commercial cultivation in 1972. Since then, many high-yielding new rice varieties have been developed. It is estimated that the high-yielding new rice varieties were planted on 55 % of paddy field in 1977. The rice production was maintained at 4×10^6 tons level before 1972, but it has drastically increased by the introduction of the high-yielding new rice varieties. It was reported that the rice production attained the self-sufficiency target of 6×10^6 tons in 1977. The production increase in other crops is insignificant. The average annual crop production between 1972 and 1977 was 4.7×10^6 tons of rice, 1.6×10^6 tons of barley and wheat, 0.3×10^6 tons of pulses, 0.6×10^6 tons of potatoes, 2.9×10^6 tons of vegetables and 0.6×10^6 tons of fruits.

Stock grazing and sericulture are generally side-businesses of farmers. There were 1.5×10^6 of Korean cattles, 1.5×10^6 of pigs and 30×10^6 of chickens in 1977. Milk cows were 109×10^3. Silkworms are raised by 20 % of farmers.

Most irrigation facilities are maintained by groups of farmers in the Farmland Improvement Associations (FLIAs) or traditional cooperatives. FLIA is a legal personnel established by the approval of the Minister of Agriculture and Fisheries based on the application of more than 20 farmers in a particular proposed project area. The government subsidy of up to 70 % of construction cost and a loan repayable in 30 years at 3.5 % of interest rate after 5-year grace are available for the implementation of irrigation project. There were 127 FLIAs managing 1,376 projects (464,442 ha) in 1976. The membership was 701,292. The Agricultural Development Corporation (ADC) identifies possible FLIA projects and undertakes the engineering service for the construction of FLIA projects.

The drought damage in 1967 and 1968 was serious. Rice production dropped to 3.6×10^6 tons in 1967 and 3.2×10^6 tons in 1968, being 10 % and 20 % reduction compared with average year production of 4×10^6 tons. After the continuous drought, various measures were taken to improve inadequate irrigation facilities: Movable pumps were introduced, and weirs, tubewells and infiltration galleries were constructed, but they were mostly temporary measures. Some facilities are still insufficient in their capacities and some have been deteriorated. Continuous effort has been made for the improvement of water management. In 1977, 1,440 middle and small scale irrigation projects of 64×10^3 ha in total area were constructed with a cost of ₩ 35.2×10^9. For 11 large scale agricultural development projects under construction, total ₩ 41.9×10^9 was invested. Now, 85 % of paddy field is regarded as fully irrigated and land consolidation has been provided for 23 % of paddy field.

The National Agricultural Cooperative Federation (NACF) serves for the agricultural input supply, credit supply and marketing. It supplies entire chemical fertilizers. NACF credit is available for 25 % of fertilizer cost at an interest rate of 8.5 %. The principal may be paid by grains. Another credit is for 70 % of procurement cost of farm machinery repayable in five years at an interest rate of 9 %. The Government collects most grains and pulses from farmers and sells them to the retailers through NACF sales centers.

The Saemaeul movement for the rural development initiated by the government in 1971 has become a farmers' movement over the country for the modernization of living and farming conditions at village level mobilizing the labor in the off-farm season. Until 1977, the Government invested ₩ 306×10^9 for improvement of farm road, domestic water supply system, public facilities and small-scale irrigation facilities. Under the Saemaeul movement between 1971 and 1977, 43,060 km of farm roads, 63,927 small bridges, 9,518 small farm ponds, 20,085 small weirs, 4,002 km of feed canals were constructed, 406×10^3 ha were afforested, 2.7×10^6 houses including non-farm houses were rebuilt, 18,921 small scale domestic water supply systems were constructed, and 34,665 storage houses were constructed.

Agricultural data in recent years are summarized in Table 6 and more details are described in ANNEX F.

2.4 Infrastructure

The total length of roads in Korea was 45,600 km including 1,200 km of express highway, 8,200 km of national roads and 36,200 km of provincial roads in 1977. About 50 % of national road and 70 % of provincial roads are unpaved. The inland transportation has been greatly improved by the express highways which have been constructed since late 1960s. It is scheduled to extend the express highway network to 1,700 km by 1991.

The railway system connects all major cities. The total length of railway was 5,710 km, of which 14 % was electrified by 1977.

The domestic airlines connect eight cities. Gimpo, Busan and Jeju are the international airports.

There are 1,980 post offices and 50 telegraph and telephone offices over the country.

KECO operates the power supply system covering the country. The power generation facilities in KECO system were 5,781 MW in total installed capacity in 1977. The composition of the installed capacity was 72 % of steam power, 16 % of combined cycle, gas turbine and diesel power and 12 % of hydropower. The Gori power station of 587 MW was put in service in July, 1978, as the first nuclear power plant in Korea. The Cheongpyeong pumped-storage power station of 400 MW is under construction. Its first unit of 200 MW will be put into operation in 1979 and the second unit of 200 MW will be completed in 1980. Energy sold by KECO was 22,833 GWh in 1977.

The municipal water supply systems of 4.4×10^6 m^3/day in total capacity supplied to 181 municipalities in 1976. The supply increased at an average annual rate of 15 % between 1971 and 1976. The pipe-served population was 17.9×10^6 corresponding to 50 % of total population. The supply was 3.9×10^6 m^3/day, or 220 litres per capita a day. More than 50 % of the supply was for Capital Seoul where the service factor was 94 % and the per capita supply was 304 litres per day. Industrial water supply systems have been constructed by MOC and city governments recently. There were industrial supply system of 747×10^3 m^3/d in total capacity for 15 industrial estates.

Effort is being made to establish sewerage systems. About 21 % of Seoul was provided with sewerage system in 1976, but the sewerage system is less developed in other cities.

2.5 Water Resources Development

Irrigation development in Korea has a long history. In 1976, there were 15,708 reservoirs irrigating 413 x 10^3 ha, 1,322 pumping stations serve for 110 x 10^3 ha of paddies and 14,014 weirs supply 120 x 10^3 ha. In total including other types of irrigation, about 1,080 x 10^3 ha of paddies are regarded as fully irrigated. The Government of Korea is promoting the land consolidation for the saving of labor and more effective water management. Some old reservoirs are in short of capacity. Uncertain water supply will still be a problem, while the high-yielding new rice variety requires more sophisticated water management.

Floods resulting from quasi-stationary fronts and typhoons cause damages every year. According to MOC statistics, the annual average flood damage in the recent 10 years amounted to $ 80 x 10^6. Of the legal rivers of 30,300 km, 20,600 km has been regarded as requiring improvement of which 5,900 km has been improved in 1977. MOC is preparing comprehensive river improvement plans for major rivers and is constructing a large scale river improvement project in the Nagdong river utilizing a loan from ADB.

Hydropower development was expedited to stand with the serious energy shortage in 1960s. The Chuncheon and Uiam power stations were constructed. The Hwacheon and Cheongpyeong power stations were strengthened in their capacity. Hydropower in more recent years has been developed as a component of multipurpose dam development. A list of power generation dams is shown in Table 7.

The Government of Korea has been paying attention to the systematic development of land and water resources to prepare for the future economic development and promulgated the comprehensive national land development plan as the Presidential Decree No. 26 in 1971. The water resources development is one of the important component of the plan.

The Han, Nagdong, Geum and Yeongsan river basins surveys were carried out with assistances of overseas institutions between 1966 and 1971. The Namgang multipurpose dam was completed in 1970. The multipurpose dams with large storage capacities such as the Soyanggang, Andong and Yeongcheon dams were completed in 1970s, and the Daecheon and Chungju dams under construction are all constructed for the maximum use of water resources based on the results of basins surveys. The Government of Korea is going to implement the Habcheon dam or the estuary barrage in the Nagdong river utilizing IBRD loan. The multipurpose dams are constructed and operated by ISWACO. Table 8 shows the multipurpose dams in Korea.

2.6 Rationale of the Study

Various measures will continuously be taken to meet water demand more adequately. Increased water use in a place in a basin will affect other water uses in the downstream by depleting more or less the river flow. Moreover, it is estimated that M&I water demand in the downstream reaches of rivers will grow large. The existing dams will not be capable of supplying all the demand in some time in the future. It is necessary to prepare for the future water shortage by ordered construction of storage dams.

The flood control is becoming more important as the land use along the rivers is intensified. Well located dams will contribute to the flood control in combination with river improvement and drainage.

The energy demand in Korea will have to be met predominantly by fossil fuel in the future. In this connection, hydropower to be made possible by construction of dam will be desirable to save fossil fuel as much as possible.

The present study will make clear the time and scale of dam construction for the future, based on updated projection on the water resources development.

3 THE THREE RIVER BASINS

3.1 River Systems

The Han river basin of 26,200 km^2 excluding the Imjin river basin is bounded by the Taebaeg mountains in the north-northeast, the Sobaeg mountains in the south-southeast, undulating hills in the southwest and the Gwangju mountains in the west-northwest. The northern part of the basin is located beyond DMZ. The Charyeong mountains cross the river basin in the northeast-southwest direction.

The main Han river is composed of the north Han, south Han and lower Han.

The north Han river, originating at about El. 1,200 m in the Taebaeg mountains in north Korea, runs 188 km approximately southward across DMZ and joints with the Suib river. Then it takes course generally to the south-southwest among the mountains of Els. 1,000 to 1,250 m for 133 km toward the confluence of the north and south Han rivers. The main tributaries of the north Han river are the Soyang river and Hong river both taking courses westerly. The catchment area of the north Han river is 10,698 km^2. There are five dams in the north Han river system. They are the Hwacheon with the tailwater surface (TWS) of El. 103 m, Chuncheon (TWS El. 74 m), Uiam (TWS El. 54 m) and Cheongpyeong (TWS El. 26 m) in the north Han river and Soyanggang (TWS El. 81 m) in the Soyang river.

The uppermost stretch of the south Han river is branched into some tributaries which are originating from the Taebaeg mountains. The south Han river runs in the southwesterly valley between the Charyeong and Sobaeg-Noryeong mountains of Els. 1,200 to 1,600 m being jointed by the Sucheon river from the right. At the Chungju damsite, the river length is 284 km from the origin and the river bed is at El. 55 m. The south Han river is joined by the Dal river from the left at 12 km downstream of the Chungju dam and it takes course generally to the northwest until it joins with the north Han river across the Charyeong mountains. The south Han river has a catchment area of 12,318 km^2 and a river length of 396 km.

The river stretch of 92 km running west-northwest from the confluence of the north and south Han rivers to the estuary is the lower Han river. The tailwater surface of the Paldang dam which is located a little below the confluence is at El. 10.6 m.

The Nagdong river basin of 23,656 km^2 is bounded by the Taebaeg mountains in the east, low hills of the Daehan strait coast in the south, and the Sobaeg mountains in the west and south. The average ground elevation is as low as El. 230 m, but massif at the southern end of the Sobaeg mountains is high: Mt. Jiri (El. 1,915 m) is the highest peak in the main land.

The Nagdong river, originating near Mt. Taebaeg (El. 1,549 m), flows southward for 170 km to the Andong dam where the river bed is as low as El. 92 m though the river length to the estuary is 342 km. The river is joined by the Banbyeon river from the left at 2 km downstream of the Andong dam and takes course westerly for 66 km until it is joined by the Naeseong river from the right. Then the Nagdong river takes a course generally to the south for 210 km to the confluence of the Nagdong and Nam rivers, where the river bed is at approximately El. 0 m. In this stretch, the Nagdong collected some large tributaries such as the Wi and Geumbo rivers from the left and the Bug, Gam, Hwang and Nam rivers from the right. From the confluence of the Nagdong and Nam rivers, the Nagdong river runs to the east and finally flows to the south toward the estuary. The total length of the river is 512 km. There is a delta of about 15×10^3 ha at the estuary.

The Seomjin river basin of 4,897 km^2 is bounded by the southern end of the Sobaeg mountains in the east, coastal hills in the south, 600 to 1,200 m high mountains in the west and the Noryeong mountains in the north. The basin is rugged.

The Seomjin river originates from Mt. Palgong (El. 1,151 m). Running for 87 km to the west-southwest, it enters in the Seomjingang dam. Thereafter the Seomjin river flows for 76 km to the south-southeast and joins with the Boseong river which runs from the south-southwest with a catchment area of 1,319 km^2 and river length of 126 km. From the confluence of the Seomjin and Boseong rivers, the Seomjin river takes easterly course, winds to the south and drains into the Gwangyang bay. The river length is 225 km.

3.2 Climate

The climate of Korea has distinct seasons. In winter from November to March, it is cold and dry with north to northwest winds. April and May are spring still dry but warm with south winds. Wet and hot summer continues from June to the middle of September with south to southwest winds. Autumn is from mid-September to October cool with north winds.

The average annual rainfall between 1962 and 1976 was calculated to be 1,272 mm for the Han river basin (71 raingauges), 1,168 mm for the Nagdong river basin (71 raingauges) and 1,403 mm for the Seomjin river basin (13 raingauges) based on MOC rainfall data (Refs. 1 & 2). An isohyetal map for the three river basins is presented in Fig. 4.

The studied area is about 400 km long in the north-south direction. Taking into account the regional difference in the agroclimatic conditions, the area was divided into five agricultural zones; the Han river basin, northern Nagdong river basin, central Nagdong river basin, southern Nagdong river basin and Seomjin river basin.

Data at the meteorological stations each representing an agricultural zone are as shown in Table 9. The annual average air temperature is the lowest of 11°C in the Han river basin and the highest of 14°C in the southern Nagdong river basin. The lowest temperature usually occurs in January and the highest temperature occurs in August. The difference in monthly mean air temperature in January is 6°C among the five zones. The annual mean relative humidity ranges between 67 % and 74 %. Pan evaporation ranges between 1,109 mm and 1,361 mm, the highest being toward the central Nagdong river basin. The annual rainfall is between 1,014 mm and 1,477 mm, the smallest being in the central Nagdong river basin. The rainfall concentrates in June to September especially in the northern part of Korea reflecting the continental climate. The sunshine hours are 5.8 to 6.3 hours. It is longest in April to June and the shortest in July to September. The wind velocity is 2.2 to 4.4 m/s on an average. The frost period is generally from mid-October to mid-April elongated to the north.

3.3 Hydrology

The hydrological network in Korea is administrated by MOC and the data are published annually (Refs. 1 and 2). There were 102 water level gauges in the three river basins in 1976; 31 in the Han river basin, 59 in the Nagdong river basin and 12 in the Seomjin river basin. Some gauges have daily water level records since 1906, but the records of most gauges are short or interrupted. The records of flow measurement are generally too scarce to construct rating curves except for some gauges in the Nagdong river basin, in which the hydrological observation has been intensively carried out by ISWACO for KOR 16 and KOR 72 since 1967.

A hydrological study was carried out to estimate the inflow into the proposed dams and the run-off at the water level gauges which were incorporated in the water budget analysis. The inflow into some existing dams was also calculated if necessary for the evaluation of the proposed dams.

The study period was set in the 15 years period of 1962-1976, because basic data are relatively accurate in this period. Data in MOC Hydrological Annual Reports and those provided by ISWACO were analyzed for various gauges and sorted in view of the accuracy and continuity of the records. Short interruptions of records were supplemented by the collection between the records of different stations or between rainfall and run-off. Estimated run-off records at nine gauges were selected for further study. The monthly inflow and outflow records at four existing dams in KECO Annual Report of Electricity were also incorporated, through their background seemed rather weak. The locations of the selected gauges and dams are shown in Fig. 5 and the basis of the estimated discharge at each gauge or dam are shown in Table 10.

The run-off records at the selected stations were converted to the run-off records at the proposed damsites by means of the ratios of basin rainfalls. The correlation between the selected stations and each proposed damsites was as shown in Table 11.

The basic gauges for the water budget analysis were selected. They are the Goan and Jeongseon in the Han river, Waegwan, Changri and Jindong in the Nagdong river, and Abrog in the Seomjin river. A 12-month period from October, 1967 to September, 1968 was selected as the standard dry year for the water budget analysis, because the estimated run-off at the above-mentioned gauges showed the smallest in the period during 15 years from 1962 to 1976.

The catchment area, average annual basin rainfall and average annual run-off for the selected stations and proposed and existing damsites were estimated as shown in Table 12. Details of hydrological analysis and 15-year monthly run-off tables are compiled in ANNEX B.

Flow mass-curves were prepared based on the estimated run-off record and they were used for the reservoir operation study in Chapter 6 and to construct storage-draft curves in Fig. 6, in which semi-theoretical curve proposed by KOR 16 are also shown. The storage-draft curve shows the rate of regulated flow corresponding to an arbitrary storage capacity based on the long-term variation of river flow.

3.4 Soils

A reconnaissance soil survey was carried out by ORD with an assistance by UNDP/FAO KOR 13 in 1964-1969 and the reconnaissance soil map covering whole Korea was completed in a scale of 1/50,000 in 1971. The reconnaissance soil map shows 19 mapping units subdivided into 52 mapping subunits, each of which is a soil association of some soil series. The legends of mapping units of the present study concern are as shown in Table 13. The extent of soils was calculated in accordance with the above-mentioned subunits for 19 sub-basins in the Han river basin, 26 sub-basins in the Nagdong river basin and five sub-basins in the Seomjin river basin. The results are summarized in Table 14.

The high-yielding new rice varieties will be predominant on paddy in the future. The yield of these varieties is especially sensitive to the plant nutrient holding capacity and soil moisture content. ORD established criteria for paddy soil classification with regard to the suitability and productivity grade of the high-yielding new rice cultivation as shown in Table 15, based on the results of regional cooperative yield trials which were carried out in 1976 and 1977 (Refs. 3 & 4). In the table, unripe paddy field is characterized by coarse textured and non-stratified soils which are derived from siliceous crystalline materials and extend in valleys between rolling lands as well as hilly and mountainous areas. The paddy soils in the sub-basins were classified based on these criteria. The results are summarized for the five agricultural zones in Table 16.

A detailed soil survey has been conducted by ORD since 1975 with the completion target of 2,651 x 10^3 ha by 1979. By the end of 1978, about 67 % was completed. ORD prepared a land capability classification criteria for the utilization of detailed soil map, based on USBR system (Ref. 5). Applying these criteria, the potential land use pattern was evaluated for the sub-basins. A summary of the outcome is as shown in Table 17. Details are presented in ANNEX E.

3.5 Regional Agriculture

Agricultural data in the five agricultural zones are listed in Table 18.

The farm population in the three river basins was 5.1 x 10^6 and the number of farm household was 931 x 10^3, both approximately corresponding to 40 % of the national total in 1976. The average family size was 5.6 persons in the Han, northern Nagdong and Seomjin river basins being larger than that in the central and southern Han river basin which was at the national average of 5.3 persons. The average land holding size was 1.17 ha in the Han river basin, 0.99 ha in the northern Nagdong river basin, 0.90 ha in the central Nagdong river basin and 0.85 ha in the southern Nagdong and Seomjin river basins, respectively. The holders of 0.5 to 1.5 ha were more than 50 %.

The cultivated area in the three river basins was 914 x 10^3 ha, comprising 505 x 10^3 ha of paddy and 409 x 10^3 ha of upland.

The second crop on paddy is normally barley or wheat. The multiple crop index on paddy was 1.65 to 1.66 in the southern areas but it was 1.32 in the northern Nagdong river basin and 1.17 in the Han river basin in 1976. Barley, wheat and pulses are the main crops on upland. The multiple crop index on upland was the highest of 1.58 in the southern Nagdong river basin and the lowest of 1.06 in the Han river basin.

The proportion of high-yielding rice varieties on paddy has increased as shown in Table 19. It reached 50 % level in the central and northern zones of the Nagdong river basin in 1976.

The average crop production in 1972-1976 in the three river basins was 1,718 x 10^3 tons of rice, 693 x 10^3 tons of barley and wheat, 147 x 10^3 tons of pulses, 618 x 10^3 tons of potatoes, 1,268 x 10^3 tons of vegetables and 302 x 10^3 tons of fruits representing 30 to 40 % of the national production as shown in Table 20.

More details are described in ANNEX F.

3.6 Cities and M&I Water Supply

The locations of the municipal and industrial (M&I) water demand centers are shown in Fig. 7.

There are nine cities in the Han river basin. The total population in these cities was 9.6 x 10^6 in 1976, corresponding to 80 % of the basin population of 11.9 x 10^6. The population in Capital Seoul was 7.3 x 10^6 with an annual growth rate of 5.4 %. Seoul-Incheon metropolitan area includes Seoul, Incheon (830 x 10^3), Anyang (150 x 10^3) and Suweon (240 x 10^3, outside the basin). Industries in the metropolitan area are heavy industries such as petrochemical, heavy machinery and thermal power in Incheon and light industries such as textile, electrical equipment, machinery and food processing in Seoul, Suweon and Anyang. There are medium size cities such as Euijeongbu, Seongnam and Bucheon surrounding Seoul. Chuncheon city is the capital of Gangweon Do located in the middle stretch of the north Han river. Weonju and Chungju are the centers of commerce. Along with the decentralization policy, a new light and chemical industrial town is being constructed at Banweol under the fourth 5-year plan.

The pipe-served population in the Han river basin including Suweon was 8.7 x 10^6 and the municipal water of 2.4 x 10^6 m^3/day was supplied in 1976. The Yeongdeungpo industrial water supply system supplied 110 x 10^3 m^3/day of water to the Yeongdeungpo industrial district of Seoul in 1976. The capacity was expanded to 130 x 10^3 m^3/day in 1977. The

Suweon/Anyang industrial water supply system was installed in 1974 with a capacity of $100 \times 10^3 m^3$/day. Most M&I water demand is presently depending on the lower Han river, in which the pollution has become a problem. The Metropolitan Water Supply Project is under construction with a capacity of $1.2 \times 10^6 m^3$/day to be completed by the end of 1978 and additional $1.4 \times 10^6 m^3$/day by 1981. Through the pipeline of this Project, water in the Paldang reservoir at the upstream end of the lower Han river will be supplied to Seoul, Incheon, Bucheon, Suweon, Anyang, Seongnam and Banweol.

The total population in five cities within the Nagdong river basin was 1.8×10^6, corresponding to 30 % of the basin population of 6.0×10^6 in 1976. Daegu (1.4×10^6), the capital of Gyeongsang-bug Do, is the inland commercial and industrial center having textile and other light industries. Gumi is a new industrial base of electronics and textile. There are seven cities located in the coastal areas adjacent with the Nagdong river basin; Busan (2.6×10^6), Ulsan (270×10^3) and Pohang (152×10^3) in the eastern coast, and Masan (425×10^3), Jinhae (104×10^3), Samcheonpo (60×10^3) and Chungmu (68×10^3) in the southern coast. Busan special city is also the capital of Gyeongsang-nam Do. It is inhabited by ship-building, chemical, car-assembling, electronics, rubber and food processing industries. Ulsan, an old port, has been developed for heavy and chemical industries such as oil-refinery, petrochemical, fertilizers, ship-building, thermal power and car-assembling industries since 1968. Pohang is a new iron and steel industrial city. The steel mill was completed with a capacity of 1×10^6 tons/year in 1973 and it has expanded to 5.5×10^6 tons/year by the end of 1978. The final capacity will be 10×10^6 tons/year. Masan is a free export city having a light industrial complex. The major industries in Jinhae are fertilizer, edible oil, slate and PVC industries. Samcheonpo was originally a fishing port, but light industries such as food processing, machinery and textile industries has been gathered in these years.

Major cities in the coastal areas depend M&I water on the Nagdong river, Ulsan and Busan take water from Mulgeum near the estuary of the Nagdong river. Masan also takes water from the Nagdong river. Pohang will be supplied by the Yeongcheon dam which is nearly completed in the

Guemho river, a tributary of the Nagdong, by MOC. The pipe-servied population depending on the Nagdong river of 4.9×10^6 was supplied with 940×10^3 m^3/day in 1976. Busan supply was 550×10^3 m^3/day to 2.4×10^6 persons and Daegu supply was 260×10^3 m^3/day to 1.3×10^6 persons in 1976. Daegu industrial water supply system of 35×10^3 m^3/day depending on small reservoir is in short of capacity. Some factories depend on municipal water and private tubewells. Gumi industrial water supply system has a capacity of 50×10^3 m^3/day. City office estimates that the industrial water requirement will reach 155×10^3 m^3/day in 1991. Most factories in Busan depend on the municipal water supply, because the industrial water supply system is small of 5×10^3 m^3/day in capacity. Masan industrial water supply system depending on the Nagdong river supplies Masan, Jinhae and Changweon. Ulsan industrial water supply system of 450×10^3 m^3/day was installed in 1977. Its intake is located at Mulgeum in the Nagdong river. Pohang pipeline of 220×10^3 m^3/day from the Yeongcheon dam will be completed in 1979.

The population in the Seomjin river basin was 870×10^3 in 1976. There is neither city nor significant industry within the basin. Gwangju city (625×10^3) in the Yeongsan river basin adjacent to the west of the Seomjin river takes M&I water from the Dongbog dam in a tributary of the Seomjin river. The Dongbog dam will be reconstructed from 1979 to increase the supply to Gwangju from 100×10^3 m^3/day to 350×10^3 m^3/day. Yeocheon Petrochemical Industrial Estate was developed on the southeastern coast of the Gwangyang bay, to which the Seomjin river drains. There are a series of petrochemical plants, an oil refinery, a fertilizer plant, a thermal power plant and petrochemical-allied industries. The Sueo dam presently supplies M&I water to Yeocheon through the 56-km long pipeline (250×10^3 m^3/day) of Yeocheon/Gwangyang Industrial Water Supply System as shown in Table 21, while the water demand nearly reached the present capacity of the pipeline. The Sueo dam has a catchment area of only 49 km^2. Most water is, therefore, lifted from a pumping station at El. 3.5 m in the Seomjin river to the Sueo reservoir. Gwangyang area of 3,570 ha to the north of Yeocheon is going to be developed for the iron and steel industry and petrochemical industry. The Yeocheon and Gwangyang industrial areas constitutes the Honam Chemical Industrial Estate along the Gwangyang bay coast. Other towns in the southern coast adjacent to the Seomjin river basin are Suncheon and Yeosu. According to a long-term plan by MOC (Ref. 13), the southern coast areas will seek M&I water resources in the expansion of the Yeocheon/Gwangyang Industrial Water Supply System, construction of the Yeonggye dam with a catchment area of 133 km^2 in the Isa river and a diversion from the Boseong river in which the proposed Juam dam site is located. This pipeline will also serve for the municipal water supply in Gwangyang and Yeosu areas in the future.

More details are presented in ANNEX H.

4 PROSPECTIVE LAND AND WATER RESOURCES DEVELOPMENT

4.1 Agricultural Land Development

The expansion in the areas of both paddy and upland has been insignificant. This will continue to the future because of physical and social limitations. Future land development would be found in more reliable irrigation on paddy for a stable rice production, land consolidation for mechanization, labor saving and better water management, and upland irrigation.

A projection was made for the future irrigation and land consolidation for each sub-basin based on the historical trend which were derived from Refs. 6 and 7. The cultivated areas were divided into five categories by the irrigation facilities as shown in Table 22 in view of the different consumption patterns of the basin water resources. The existing plans for irrigation projects were taken into account. Upland irrigation in 2001 was assumed to be 10 % to 15 % of upland in the sub-basins near urban areas and 5 % of upland in the other sub-basins, because it has been limited to only some apple orchard in the Nagdong river basin. The land consolidation is still at the initial stage of development. It was assumed that the land consolidation would be provided on all paddy of a land gradient of up to about 3 %. The area directly depending on the rivers downstream of the proposed damsite was estimated based on data prepared by ADC. The maximum pump water head was assumed to be 40 m in the ADC data.

The results of agricultural land development projection for each agricultural zone are summarized in Table 23 to 27 and are illustrated in Fig. 8. Detailed projection is compiled in ANNEX G.

4.2 Cropping System and Irrigation Water Requirement

A cropping system with rice as the summer crop and other crop, mainly barley and wheat, as the winter crop is called the two cropping in Korea. The ratio of two cropping to the single cropping on paddy in the recent five years was assumed for the future cropping on paddy, because this ratio seems to have already been determined by the local climatic conditions. The high-yielding rice varieties will be cultivated on the most suitable and suitable soils (grades 1 to 4 in Table 16) in the future. The high-yielding varieties are rather weak to the pests and diseases. The ratio of the crop area of high-yielding rice varieties to total paddy was assumed to be the proportion of grades 1 to 4, but a little lower in the Seomjin river basin where pests and diseases prevail. The historical and future cropping patterns on paddy were estimated as shown in Fig. 9.

The irrigation water requirement was calculated under the meteorological condition from October, 1967 to September, 1968 which was selected for the water budget analysis because of the smallest run-off between 1962 and 1976 as explained in Section 3.3. Major assumptions were as follows:

(1) The consumptive use on paddy was estimated from pan evaporation record. The consumptive use coefficient was taken from KOR 16 which was based on many experimental results (Ref. 8). The consumptive use coefficient of the high-yielding rice varieties was assumed to be the same as that of traditional varieties.

(2) Paddling water requirement was assumed to be 150 mm.

(3) The effective rainfall on paddy was estimated by means of daily moisture balance method with the decreasing depth of 8 mm/day in May, 9 mm/day in June and July, 11 mm/day in August and 9 mm/day in September. Rainfall beyond 60 mm/day and less than 5 mm/day were regarded as ineffective and no rainfall was assumed for October.

(4) The percolation rate on paddy was assumed to be 5 mm/day in May and June, and 4 mm/day for July to October based on the survey results by KOR 16 (Ref. 8).

(5) The irrigation efficiency for paddy was assumed to be 65 % which was a combination of conveyance efficiency of 90 % and application efficiency of 72 %.

(6) The water requirement on the irrigated upland was estimated assuming an orchard. The evapotranspiration was calculated by a modified Penman formula. The effective rainfall was calculated

by means of the daily moisture balance method and the irrigation efficiency assumed was 55 %.

The estimated irrigation water requirement is as summarized in Table 28. It is noted that the figures in Table 28 do not necessarily apply to the design of a specific project but estimated for the hydrological year from October, 1967 to September, 1968.

4.3 M&I Water Demand Projection

A population projection was made for 116 municipalities which were or would be depending their M&I water on the three river basins. The historical growth trend was analyzed based on population censuses in 1955, 1960, 1966, 1970 and 1975. The projection method was in principle the ratio method, but the projections by the municipality offices were esteemed as far as possible. The results of population projection are summarized in Tables 29 to 31. The population of municipalities depending on the Han river will increase from 10×10^6 to 16×10^6 between 1976 and 2001. The population of municipalities depending on the Nagdong river will increase from 6×10^6 to 11×10^6 in the same period, but the population increase outside of the basin will be predominant. The population within the Seomjin river basin will be decreased gradually, but, by a large increase in population in Suncheon, Gwangyang, Yeosu and Yeocheon, the population of municipalities depending on the Seomjin will slightly increase. The non-water-served population, though excluded from the above-mentioned municipalities population, was also counted in projecting the future water demand.

In estimating the municipal water requirement in the future, the standard service factor and per capita use prepared by MOC (Ref. 9) were applied with some adjustment based on data in 1971 and 1976 as shown in Table 32.

The industrial water requirement in 21 industrial areas including planned areas was projected based on the historical data, expansion plans and projections in previous reports. The water requirement in the expansion areas was estimated based on the water requirement per ha by kind of industries contemplated.

The projected M&I water requirement is summarized in Table 33. M&I water demand in the Han river will increase from 1 x 10^9 to 4 x 10^9 m^3/year between 1976 and 2001 at an annual increasing rate of 5.4 %. The municipal water demand will be 60 % and the industrial water demand will be 40 % of the total demand in 2001. The industrial water demand will grow at an annual rate of 8.1 %. M&I water demand in the Nagdong river will increase from 0.5 x 10^9 to 2.5 x 10^9 m^3/year during 1976-2001 at an annual increasing rate of 6.4 %. The demand outside of the basin will be 72 % of the total in 2001. M&I water demand in the Seomjin river will increase from 20 x 10^6 m^3/year in 1976 to 530 x 10^6 m^3/year in 2001. The industrial water requirement outside of the basin will be the majority being 84 % of the total.

The details of M&I water demand projection are described in ANNEX H.

4.4 River Maintenance Flow

The requirement for the river maintenance flow was assumed based on previous studies, which vary with regard to the depth by river basin.

HRBS estimated in 1971 that the minimum flow needed to prevent the salinity hazard in the lower Han river was 32.6 m^3/s at Paldang (Ref. 10). The net water loss between Paldang and estuary was preliminarily estimated as shown in Table 34.

The total water taken for the irrigation and M&I water supply in the lower Han river basin will increase from 68 m^3/s in 1968 to 92 m^3/s in 1981 and 118 m^3/s in 2001. Net water loss in the Han river basin will however reduce from 43 m^3/s in 1968 to 42 m^3/s in 1981 and 31 m^3/s in 2001, because a large amount of water will be diverted for M&I water supply from the Paldang dam to the lower Han river basin through the new Metropolitan Water Supply System. There will be no salinity problem in the future, if the minimum flow needed to prevent the salinity hazard under the condition of 1968 should be maintained in the future. The minimum flow from the lower Han river basin of 2,336 km^2 is estimated to be 25 to 30 m^3/s in the irrigation period. The water requirement for the sea water repulsion is estimated to be 15 to 20 m^3/s by deducting the 1968 net water loss of 43 m^3/s from the sum of 25 to 30 m^3/s and 32.6 m^3/s, if the estimate by HRBS is valid. This value seems to be too small.

A survey over the Han river in 1977 by the Seoul City Office disclosed that the lower Han river had been polluted by the industrial waste from tributaries and sewerage from Seoul. The value of BOD at the municipal water intake at Yeongdeungpo increased from 7 to 8.5 ppm during 1973-1977. No better effect on the pollution control can be expected from sustaining the river maintenance flow of 32.6 m^3/s, because it approximately corresponds to the minimum natural flow at Paldang.

These considerations imply that the river maintenance flow of 32.6 m^3/s is underestimated and needs modifications based on a detailed survey and analysis. This value was however taken up in the present study, only because no other estimate had been available. This problem will be discussed again in Section 6.2.

There are important intakes near the estuary of the Nagdong river as shown in Fig. 10. M&I water intakes for Busan and Ulsan are located at Mulgeum. The irrigation intakes for the delta area are located at Weolchon and Daedong. The Weolchon intake can afford to supply the delta area, even if the Daedong intake is closed in a dry spell.

A computer analysis by KOR 72 resulted the water requirement for the sea water repulsion to be 44 m^3/s at just downstream of Weolchon from May to September and 38 m^3/s at just downstream of Mulgeum from October to April, respectively, assuming the critical salinity to be 200 ppm for M&I intake and 1,200 ppm for irrigation intake (Ref. 11). KOR 72 also studied the oxygen balance in the Nagdong river and concluded that the major sources of water pollution were Daegu and Gumi and the minimum river flow for the pollution control would be as shown in Table 35, assuming that sewage treatment plant would be installed at Gumi and Daegu with an efficiency of 90 % (Ref. 11). The river maintenance flow in this study was assumed as that showing greater water deficit between the water requirements for the sea water repulsion and pollution control as estimated by KOR 72.

It has been estimated that the water requirement to maintain the salinity in the Seomjin river below 150 ppm was 5.5 m^3/s at Songjeong and 20 m^3/s at Hadong (Ref. 12). A water budget calculation based on these figures resulted that the Seomjin river had been already in a serious shortage of water, seemingly contradictory to the actual situation. The intake for the Yeocheon/Gwangyang Industrial Water Supply System (see Section 3.6) was constructed at 6.5 km upstream of Hadong on the basis of the river maintenance flow of 4 m^3/s at just downstream of the intake (Ref. 13). This value was assumed for the present study.

4.5 Power Market

The gross power generation was 26,587 GWh and the maximum output was 4,187 MW in the KECO power supply system in 1977. The annual peak demand usually appears in December, but the demand in July and August growing high. The annual growth rate of power demand has been declined, but it is still high of 18 %. The composition of energy sold is 13.1 % for lighting, 8.8 % for power under 99 kW, 77.5 % for power over 100 kW and 0.6 % for agriculture. According to 1978 power demand projection by KECO, the power demand will increase at an annual rate of 12.7 % between 1977 and 1996 and the maximum demand will exceed 40 GW in 1996.

The Government of Korea established a long-term power development scheme (1977-2000) in January, 1978 as summarized in Table 36. The scheme envisaged to rise up installed capacity in KECO system to 80 GW by 2000. The major generating facilities would be 41 nuclear units and 21 thermal units. They would constitute 86 % of the total installed capacity in 2000. These facilities will be, in nature, base-load plants. The pumped-storage power plants (12 %) and hydropower plants (2 %) will be assigned as the peak-load plants.

Hydropower will be the most economical in a sense of energy resources saving, but its potential is low in Korea. It would be desirable that hydropower be developed, if a dam is constructed for any purpose.

5 WATER BUDGET

5.1 Methodology

Stress has been put on the increase in the minimum river flow in planning dams in the Han river basin by the reasons that hydroelectric potential is relatively high, future water requirement will be predominantly for M&I water supply and there are large storage sites. The water budget by HRBS (1967-1971) took a view that increase in the minimum flow would enable water use through the year. The Soyanggang and Chungju multipurpose dam projects were planned based on these criteria.

Agricultural water demand is predominant having a high peak demand in the transplanting period in the Nagdong river basin where the river flow is less stable while having less storage possibilities than in the Han river basin. The water budget by KOR 16 (1967-1971) disclosed that a large water deficit would occur during the irrigation period, taking into account the seasonal variation of water withdrawals in the river basin. The Andong dam multipurpose development project was formulated based on the water budget of KOR 16.

The criteria taken by HRBS are applicable only if the demand is almost constant throughout a year. On the other hand, the criteria by KOR 16 are valid irrespective of the demand fluctuation. The criteria by KOR 16 were exclusively applied for the three river basins in the present study.

5.2 Assumptions

The original surface condition of a land is assumed as grassland. In the process that rainfall on the grassland becomes river flow, certain volume of water is lost as the evapotranspiration and percolation loss. The percolated water enters in the river in an elongated period. Certain amount of percolation loss which enters in the river in the initial portion of the period could be regarded as available as same as the rainfall which directly entered from the ground surface to the river and this is herein called the return flow. The river flow contributed by the rainfall on the grassland is consequently written as follows:

$$q = R - E - PL + RF \quad (1)$$

where, q : Contribution to river flow of rainfall on a land

R : Rainfall on the land

E : Evapotranspiration

PL : Percolation loss

RF : Return flow

If total water lost in a process that rainfall on a land becomes river flow is called the water withdrawal (W), it is expressed as follows:

$$W = R - q = E + PL - RF \quad (2)$$

In case of the river-depending paddy, the river flow is once reduced by the diversion water requirement, but ineffective rainfall on the land and return flow enter in the river. Part of conveyance and application losses also returns to the river:

$$q = R - (E - ER + PL + CL) - ER + RF$$
$$W = R - q = E + PL + CL - RF \quad (3)$$

where, ER : Effective rainfall

CL : Conveyance and application loss

Equation (3) is also valid for the downstream of the intake of reservoir-depending paddy. In the reservoir, the evaporation loss and storage are positive withdrawals, while the draft and spillout are negative withdrawals.

In case of groundwater-depending paddy, the groundwater storage functions similar to a reservoir. It was assumed that the groundwater-depending paddy shows the same withdrawal as the reservoir-depending paddy, because its area is minor.

Equation (3) is also applicable for the supplementarily irrigated paddy and irrigated upland. The water withdrawal by rainfed upland was assumed to be the same as by grassland.

Evapotranspiration and percolation loss will be at their potential value in the case of river-depending paddy and upland, if water in the river is sufficient. On the other hand, the evapotranspiration and percolation loss will be affected by the depletion in the soil moisture in the other cases, because the water sources have certain constraints. The water withdrawals except that by river-depending paddy were determined by means of 5-day moisture balance calculation under the dry year meteorological condition. Major assumptions for the calculation were as follows:

(1) There is no inflow from other area into a grassland. The field capacity is 300 mm and the wilting point is 100 mm.

(2) The supplementarily irrigated paddy is fed by an outside area three times the own area. Ponding depth is 100 mm, field capacity is 150 mm and wilting point is 50 mm.

(3) For the reservoir-depending paddy, it was assumed that the catchment area was 3.9 to 7.3 times the benefited area and the ratio of storage capacity to the benefited area was 280 to 510 mm depending on the agricultural zone on the basis of existing reservoir data as described in ANNEX G.

(4) For the consolidated paddy, percolation rate is 10 % higher than the unconsolidated paddy and irrigation efficiency is 60 % instead of 65 %. This may increase the diversion requirement by 15 % to 20 % compared with unconsolidated field but the increase in the water withdrawal is 5 % to 6 %.

The return flow for the grassland and cultivated area was assumed to be 50 % of percolation loss and 70 % of conveyance and application losses. The return flow for M&I water was assumed to be 70 % of the demand within the basin and zero for the demand outside the basin. These assumptions follow KOR 16 study.

The difference between the withdrawal by a cultivated area and that by the grassland is called the net water withdrawal. The river flow, which would occur if the existing cultivated areas are all replaced by grassland and M&I supply is zero, is named the natural flow. If a record of a measured flow at a gauge in a past year is available, the natural flow is obtained by adding the net withdrawal by the cultivated area and M&I withdrawal in the recorded year to the measured flow.

The water deficit in a projected year is the difference between the net withdrawal by the cultivated area and M&I withdrawal in the projected year and the natural flow.

The net withdrawal in the tributaries may exceed over the natural flow at a time. In such case, a deficit occurs in the tributaries and there is no water available in the main stream.

5.3 Division of Basins

In carrying out the water budget calculation, the river basins were divided into some segments, taking into account the demand condition and the location of the water level gauges.

The water budget in the Han river basin was analyzed at just downstream of the Paldang dam. No further division of basin was made, because calculations dividing the basin into the north and south Han river basins in the Interim Report resulted little deficit in the tributaries.

The Nagdong river was divided into four segments; above the Goryeong bridge, Goryeong bridge to Nam river, Nam river, and Nam river to Weolchon. The lowest point of calculation was Hadan at the estuary.

No division was made for the Seomjin river. The calculation point was Hadong in the estuary.

It was assumed that there is no outflow from the catchment areas of existing large reservoirs, for the convenience of use of results; the Soyanggang dam, Chungju dam and Andong dam. The catchment areas of Yeongcheon dam, Seomjingang dam and Dongbog dam were also assumed to be shut down, because these dams entirely divert water to other basins.

5.4 Measured Flow

The basic water level gauges used are the Goan for the Han river, Waegwan, and Jindong for the Nagdong river and Abrog for the Seomjin river. The 5-day run-off records at these gauges were converted to the downstream end of each division of the river basin by the ratio of catchment area or the ratio of basin rainfall. It is noted that the difference between the outflow and inflow at the Hwacheon dam was once deducted from the measured flow at Goan and then added to the measured flow which was estimated assuming the shut down by the Chungju and Soyangang dams. The influence by the Namgang dam was estimated and included in the measured flow which was estimated for the Nam river mouth. The spillout only was taken into account for the Boseong dam, because this dam diverts water to the southern coast.

The calculation period was a year period from October, 1967 to September, 1968 which was the driest year in 1962-1976.

5.5 Results

The net water withdrawals for the projected years are summarized on annual basis as shown in Table 37. It was assumed that the M&I net water withdrawal was constant throughout the year, while the agricultural net water withdrawal fluctuated seasonally as described in ANNEXes F & K. The river maintenance flow was assumed to be constant for the Han and the Seomjin rivers but it was assumed to fluctuate seasonally and grow yearly for the Nagdong river as explained in Section 4.4.

In the Han river basin, M&I water withdrawal is already predominant and it will grow rapidly. In the Nagdong river basin, the agricultural water withdrawal in the tributaries will be predominant through the projected years, but M&I water withdrawal depending on the main stream will grow faster than the agricultural water withdrawal. In the Seomjin river basin, M&I water withdrawal will grow fast and it will surpass the agricultural withdrawal in the near future.

The calculated water deficit in terms of the annual volume and annual peak is summarized in Table 38.

Assuming that there is no outflow from the Soyanggang dam and Chungju dam, the water deficit just downstream of the Paldang dam was calculated to increase from 262×10^6 m^3 in 1986 to $1,241 \times 10^6$ m^3 in

2001 in volume or from 71 m^3/s in 1986 to 132 m^3/s in 2001 in peak. The peak usually will occur in July 1 to 10.

The deficit in the Nagdong river basin, assuming no outflow from the Andong and Yeongcheon dams, will be 894 x 10^6 m^3, or 143 m^3/s in 1986 and 1,505 x 10^6 m^3, or 179 m^3/s in 2001. As for the river maintenance flow, the sea water repulsion is generally more critical requirement than the pollution control, but the water requirement for the pollution control sometimes causes a large deficit at the Goryeong bridge. In fact, the calculation showed that the water deficit at the Goryeong bridge is larger than that at the estuary in June 21 to 25 and August 11 to 15. The peak deficit will occur in June 16 to 20.

The deficit in the Seomjin river basin will be 72 x 10^6 m^3 with a peak of 13 m^3/s in 1986 and 238 x 10^6 m^3 with a peak of 22 m^3/s in 2001. The peak deficit period will be June 16 to 20.

Calculations were also made for the areas between the Gujeol damsite and the backwater end of the Chungju reservoir and between the Hamyang damsite and the backwater end of the Namgang reservoir, but no deficit came out.

The water deficit calculated on 5-day basis is illustrated in Fig. 11. The water deficit will usually take place in the dry periods which occur in the dry season as well as in the wet season in the Korean rivers. The water deficit will be the highest, if a dry spell occurs in the irrigation period.

The detailed calculations are compiled in ANNEX K.

6 RESERVOIR OPERATION

6.1 Operation Method

The inflow into a dam's reservoir is retained in order to produce a regulated outflow for the river downstream of the dam. The water deficit downstream will increase by the amount of inflow into the dam, if there is no outflow. The amount of regulated outflow required to meet the total water deficit is therefore equal to the water deficit without the dam plus the inflow into the reservoir. Consequently, the water supply capacity of the dam at an arbitrary time is estimated to be the regulated outflow less the inflow into the dam at that time. According to the water budget as described in Chapter 5, the water deficit will vary from time to time and it will occur only in limited periods of the year. The downstream run-off is more than enough to satisfy the requirement in the non-deficit periods. If the water supply capacity of a dam is enough to supply the water deficit at all times during the year, the outflow and the run-off together can guarantee a large enough supply to meet the entire demand which may be continuous throughout the year.

The water supply capacity of a dam at a particular time is utilized for the supply of water deficit, but only if there is a water deficit at that time. The net water supply capacity of a dam in a particular year is herein defined as the maximum water deficit to be supplied by the dam in the year, if the water supply capacity of the dam is equal to the water deficit at the time the maximum water deficit occurs and if providing the water supply capacity of the dam is not less than the deficit at any other time during the year. If there is a dam which has already been completed on the river before a proposed dam is constructed on the same river, the net water supply capacity of the proposed dam is the difference in the net water supply capacity of the two dams and that of the existing dam.

The regulated outflow of a dam is approximately constant throughout the year, if the dam is operated for the purpose of power generation. This type of operation is herein called the constant draft operation.

It will be favorable to some extent, concerning the supply for the water deficit, that the water supply capacity of the dam will be naturally larger in the dry periods than in the wet periods under the constant draft operation, but all the water supply capacity will not be utilized in supplying the water deficit.

The herein named variable draft operation is that operation which releases the regulated outflow in accordance with the water deficit. The assumed outflow is the water deficit plus the inflow in the deficit periods, and the minimum outflow in the non-deficit periods is equal to the minimum monthly inflow in the base dry year between October, 1967 and September, 1968. A dam having an arbitrary active storage capacity can meet the greatest water demand if operated by the variable draft operation method, because the regulated outflow in the variable draft operation is usually the minimum necessary for the deficit supply. However, the variable draft operation is unfavorable for the power generation, because the regulated outflow is very small during the non-deficit periods.

6.2 Operation of Existing Dams

The regulated outflow from the Soyanggang dam was estimated to be 55.5 m^3/s, assuming a constant draft operation (Fig. 17). The Chungju dam will be operated with a variable draft, taking into account the downstream water requirement. A recent estimate of the outflow from the Chungju dam in a dry year is as shown in Table 39. The regulated outflow from the Soyanggang dam and Chungju dam are superposed on the 2001 deficit in the Han river in Fig. 12. The regulated outflow of these two dams can be regarded as the water supply capacity because the deficit was calculated assuming that there is no outflow from the catchment areas of the two dams. The existing dams including the Chungju dam together will meet all the deficit in 2001. The deficit in further future will appear in July 1 to 10 and will develop in longer period.

The peak deficits (July 1 to 10) in the projected years are plotted in Fig. 16. The comparison between the extrapolated peak deficit and the supply from the Soyanggang and Chungju dams shows that the existing dams can meet the deficit until 2008.6. The assumed river maintenance flow of 32.6 m^3/s at Paldang seems to be underestimated for the sea water repulsion and maybe too small for the pollution control in the future as explained in Section 4.4. The natural discharge at Paldang in July is estimated to be 70 m^3/s excluding the flood flow. If this flow shall be maintained for the sea water repulsion and pollution control in July, the deficit build up curve in Fig. 16 will be shifted upward by 37.4 m^3/s (= 70 - 32.6). Then the existing dams will fail the supply from 2002.

The Andong dam meets the peak portion of the deficit in the Nagdong river, because it can release water with a high variation, its power station being operated as a pumped-storage power station in non-deficit periods. It was estimated that the Andong dam could meet 740 x 10^6 m^3 of deficit corresponding to 142.5 m^3/s of peak deficit which was estimated assuming no outflow from the Andong dam (Fig. 19). According to Fig. 16, an additional dam to the Andong dam will be needed from 1985, suggesting that the preparation for the construction of a new dam should be started as soon as possible.

The Government is planning to implement the Habcheon dam or an estuary barrage as the next project to the Andong dam. A constant draft operation will be carried out with an active storage capacity of 543 x 10^6 m^3 at the Habcheon dam, according to the present plan. The regulated outflow from the Habcheon dam was estimated to be 18.1 m^3/s based on a mass-curve study. The water supply capacity of the Habcheon dam is this regulated outflow less the inflow into the dam. The Habcheon dam, located below the Goryeong bridge, can supply only a limited deficit, because the water deficit at the Goryeong bridge is sometimes very large compared with that at the estuary as shown in Fig. 13. The net water supply capacity of the Habcheon dam is estimated to be 13.8 m^3/s. The water supply by the Andong dam and the Habcheon dam in 2001 is illustrated in Fig. 14.

The estuary barrage will save the water requirement for the sea water repulsion to an extent which will be determined taking into account the effect on water pollution, fishery, groundwater problem and ecological balance. In the example of the Tone river barrage in Japan, 20 m^3/s of water has been developed for the M&I water supply and irrigation by saving the river maintenance flow from 50 m^3/s to 30 m^3/s. The water budget showed that the barrage would save 560 x 10^6 m^3 of deficit, or 24.1 m^3/s in the net water supply capacity, with an assumption that the water for the sea water repulsion would no longer be needed after the construction of barrage, or, the river maintenance flow would be required only for the pollution control. The water supply by the Andong dam and the estuary barrage is illustrated in Fig. 15.

A deficit build-up curve for the Nagdong river in Fig. 16 based on June 16 to 20 deficit shows that the Andong dam and the Habcheon dam can supply all the deficit until 1990.1 and the Andong dam and the barrage can supply all the deficit until 1994.7.

The effects of the existing dams were already incorporated in the water budget in the Seomjin river. The peak deficit build-up curve for the Seomjin river was prepared as shown in Fig. 16. An extrapolation of the curve to the past indicated that deficit had occurred since 1977.

6.3 Commission Time of Proposed Dams

The time for the commission of a proposed dam in a basin will be the date beyond which the existing dams can no longer supply all the water deficit in the basin.

The commission time of a proposed dam in the Han river basin will be 2008.6 or earlier depending on the river maintenance flow requirement.

In the Nagdong river basin, the commission time will be set at 1990.1 if after the Habcheon dam, or 1994.7 or earlier if after the estuary barrage. It was estimated by KOR 72 that the water pollution would be serious problem if purification measures would not be taken at Daegu and Gumi. It was assumed that the Habcheon dam rather than the barrage would be constructed as the next project after the Andong dam, because time would be needed for taking purification measures at Daegu and Gumi and an additional study on the physical and social influence of the barrage had to be made before the construction of barrage can be started. Another dam after the Habcheon dam has been constructed will be commissioned in 1990.1.

A dam must be constructed as early as possible in the Seomjin river basin, because dry year flow is already in deficit. It was herein assumed that a proposed dam would be commissioned in 1986, taking into account the time required for the construction.

6.4 Operation of Proposed Dams

The operation methods of the proposed dams were set as shown in Table 40, taking into account the characteristics of each proposed dam. The constant draft operation was studied for all the proposed dams and the variable draft operation was considered if it is more effective for the water supply purpose than the constant draft operation. The net water supply capacity of the proposed dams and related inflow and outflow mass-curves are illustrated in Figs. 17 to 20.

The proposed Bamseonggol, Inje, Bonghwa and Hamyang damsites are located upstream of the existing dams of substantially large storage capacity. A constant draft operation only was assumed for these damsites, because no better effect on the water supply by the existing dam was expected from the variable draft operation of the upstream dams. The regulated outflow from the existing dam was estimated for the conditions with and without the proposed dam by a flow mass-curve analysis. The net water supply capacity by the proposed dam was then determined as the difference in the regulated outflow from the existing dam under the two conditions.

Both the constant and variable operations were studied for the proposed Hongcheon, Dalcheon, Ganhyeon and Imha dams. The regulated outflow for varying storage capacity was estimated by means of flow mass-curve. The net water supply capacity in the Han river was determined as the regulated outflow less the inflow in July 1 to 10 in which the deficit would be the largest. The water supply capacity of the Imha dam in the Nagdong river can be totally utilized for the deficit supply during the deficit periods owing to the variable draft operation of the Andong dam. The net water supply capacity by the Imha dam was determined maintaining the regulated outflow as constant as possible during the deficit periods for the variable draft operation.

For the Juam dam in the Seomjin river, two plans were envisaged as will be explained in Chapter 7. One is the main stream plan in which the Juam dam once releases the entire outflow into the Seomjin river and the total water demand would be met by taking water from the Seomjin river. The other is the diversion plan in which a diversion tunnel directly connected with the Juam reservoir supplies the M&I water demand in the southern coast out of the Seomjin river except 250 x 10^3 m^3/d which will be taken from the existing intake of the Yeocheon/Gwangyang Water Supply System, and the remaining demand is supplied by taking water in the Seomjin river. The outflow from the Juam dam for the main stream plan was determined based on the water deficit calculated assuming that all the projected demand takes place but there is no outflow from the Juam dam. The water deficit to be met by releasing water into the main stream for the diversion plan was estimated assuming that the M&I water requirement is reduced by the diverted supply and there is no outflow from the Juam dam. The total requirement for the regulated outflow from the dam in this case was estimated to supply the sum of the water deficit in the Seomjin river and M&I diversion requirement. Both the constant draft operation and variable draft operation were studied for the main stream plan. In the diversion plan, little power can be developed because the water head between the reservoir and M&I demand center is totally utilized to convey the diverted water and the release into the main stream is little. Therefore, the variable draft operation only was assumed for the diversion plan.

The Gujeol dam also has a certain water supply capacity, but it has no net water supply capacity because there is no water deficit downstream. Therefore, the constant draft operation only was studied in favor of power generation and the year of commission was assumed to be 1986.

6.5 Target Year

The target year of water supply was determined as the time in which the water supply by the proposed dam would become the maximum and an additional dam would be needed beyond the time. It was estimated as the time in which the peak deficit is going to exceed the net water supply capacity of the proposed dam on the deficit build-up curve in Fig. 16. For the Juam dam in the Seomjin river basin, the target years were determined based on the deficit build-up curve and deficit plus diversion requirement build-up curve under the condition that there is no outflow from the Juam dam in Fig. 21.

The storage capacity, regulated outflow, net deficit supply, year of commission and target year for the alternative scales of the proposed dams are listed in Tables 41 and 42.

The variable draft operation can meet quite a large water demand compared with the constant draft operation in the Han river basin, because the duration of the water deficit periods will be short after the water deficit has reached the net water supply capacity of the Soyanggang and Chungju dams. The difference between the two operation methods is not so significant in the Nagdong river basin, because a long lasting deficit will be assigned to the future dam, the peak portion of the water deficit having already been clipped off by the Andong dam. The variable draft operation shows a longer net water supply capacity than the constant draft operation in the case of the Juan dam main stream plan in the Seomjin river like in the Han river. The diversion plan has a smaller net water supply capacity because the diverted water is constant throughout the year.

7 DESIGN AND COST ESTIMATE

7.1 Alternative Scale Setting

The design and cost estimate were made to obtain the construction cost in a wide range of alternative sizes of the proposed dams in the Interim Report. The active storage capacity of each dam was set at 40 %, 60 %, 80 % and 100 % of the annual inflow, unless there was any constraint. The annual inflow estimated in the first stage of the study was assumed, because the hydrological study was still going on. The maximum discharge of power station was set assuming alternative plant capacity factors of 20.8 %, 31.3 % and 41.7 %. The results of these studies were herein followed with modifications in the unit construction cost of rockfill dam and maximum discharge of certain power stations. The adopted construction costs for varying size of the dam and power facilities are presented as the cost curves in ANNEX P.

As for the selection among the alternative damsites, the Bamseonggol downstream site and Bonghwa upstream site were eliminated because of landslide possibility, the Inje downstream site was omitted because of higher construction cost than the upstream alternative, and the Ganhyeon downstream site could not be investigated as the field inspection was not admitted.

The design drawings compiled in DRAWINGS are classified into the pre-feasibility design and sample design. The pre-feasibility designs were prepared for the optimum scales based on the outlines in Tables 84 and 87 of the economically justified dams at a discount rate of 8 % such as the Bamseonggol, Hongcheon, Dalcheon, Ganhyeon, Imha and Juam dams. The sample designs were reproduced from the Interim Report for the dams less economical; the Inje, Gujeol, Bonghwa and Hamyang dams (The sample design of Hamyang dam was revised). The scales of dams in the sample design are not necessarily the optimized ones but are rather arbitrary as shown in Table 43.

The design drawings, geological maps, drill logs and the seismic refraction diagrams are compiled in DRAWINGS. The other results pertaining to the geological surface exploration, core drilling and seismic exploration are described in ANNEX L. The results of the survey and tests for the construction material are presented in ANNEX M.

7.2 Design Criteria

The design flood for the diversion during the construction period was assumed to be the larger one between the experienced maximum and 50-year flood for a rockfill dam and 2-year flood for a concrete gravity dam.

The cross section of concrete gravity dam was assumed to be vertical with a bottom fillet (or 1:0.1 in the sample design) on the upstream slope and 1:0.8 on the downstream slope. The assumed rockfill dam was a central core type dam of 10 m in crest width, 1:2.4 on the upstream slope and 1:2.0 on the downstream slope.

The spillway discharge capacity was determined as capable of a 200-year flood for a concrete dam and a flood 1.2 times as large as 200-year flood for a rockfill dam, both without regulation in the reservoir.

The dam height was determined allowing a freeboard of 2 m for a concrete gravity dam and 3 m for a rockfill dam above the flood water surface.

The reservoir low water surface elevation was set allowing a clearance of 2.5 times of the headrace diameter above the 100-year sedimentation surface.

The selection between the concrete gravity dam and rockfill dam was made based on a comparison of construction cost. Note that the difference between the construction costs of the two dam types was less than 15 % for the Bamseonggol, Inje, Bonghwa, Hamyang and Juam dams, suggestive more detailed comparison in the future stage.

The power generation was studied only in relation with the constant draft operation. The installation of a running power station or the pumped-storage power station of the Andong type might be justified for the variable draft operation, but the study on this aspect was left for the feasibility study. The inclusion of power generation purpose with a 5 hour-peaking operation (plant capacity factor 20.8 %) was justified for the Bamseonggol, Inje, Gujeol (diversion plan), Hongcheon, Bonghwa and Imha dams and the power generation with a small installed capacity (18-hour operation, or 75 % in plant capacity factor) was justified for the Dalcheon, Ganhyeon, Hamyang and Juam dams. These results were taken into account for the design of proposed dams (see Tables 81 and 82).

7.3 Cost Estimate Criteria

The estimated construction cost consisted of the direct construction cost, compensation cost, engineering and administration cost and contingency.

The direct construction cost comprised the civil work cost, metalwork cost, generating equipment cost and transmission line and substation cost. The civil work and metalwork costs were estimated based on the unit prices, set by updating to 1978, which were applied for the Soyanggang, Andong and Daecheong multipurpose dams. The estimated unit prices of the Chungju dam was also referred to. The unit prices for major work items are listed in Table 44. The costs of generating equipment, transmission line and substation were estimated based on the international prices.

The compensation cost comprising the land compensation cost and ground facilities cost was estimated by MOC as explained in ANNEX O.

The engineering and administration cost was estimated to be 10 % of total direct construction cost.

A physical contingency was assumed to be 20 % of all direct and indirect costs.

All the costs were estimated at 1978 price level and no price escalation was added. The interest during the construction period was not included.

7.4 Bamseonggol Dam

The proposed Bamseonggol damsite is located in a westerly course of the Suib river 14 km upstream of the confluence of the north Han river and the Suib river. An alternative damsite located about 4 km downstream was eliminated, because the geological exploration revealed that it was located in an extensive rockslide area. The high water surface at El. 181 m of the Hwacheon dam stretches into the Suib river to about 5 km downstream of the proposed damsite. DMZ located about 18 km to the north-northeast of the damsite will limit the reservoir water surface at El. 305 m at the maximum.

The hydrological data estimated in the present study are;

Catchment area	:	583 km^2
Annual rainfall	:	1,276 mm
Annual inflow	:	509 x 10^6 m^3
Experienced maximum flood	:	3,000 m^3/s
2-year flood	:	650 m^3/s
50-year flood	:	2,500 m^3/s
200-year flood	:	3,400 m^3/s

A geological map of the damsite is shown in DRAWING No. 001. The rock is coarse grained hard granitic gneiss fresh but fissured. The riverbed is approximately El. 210 m. The left abutment is hard granitic gneiss with a slope of 30°. Many outcrops are recognized. Scree deposits below El. 240 m being underlain by terrace deposit. The thickness of these overburden was estimated to be 12 m in the bore hole DH 1. Based on the seismic exploration, it was estimated that overburden or highly loosed rock layer is 5 to 8 m thick being shallower to the upper portion and top 10 to 20 m rock is weathered.

The riverbed of 80 m in width has a 5 m-thick deposit on the left and a low water channel on the right. Fresh hard rocks expose in the right brink. The right abutment is a slope of 40° having relief. It was estimated that the rock surface was weathered for 8 to 16 m in depth under the overburden of 1 to 5 m in thickness.

There is a 300 m-long and 50 m-wide saddle of El. 310 m at the crest, at about 550 m southeast of the damsite. The crest is exposed granitic gneiss with fissures which seem to be loosened probably needing some treatment for waterproof.

The proposed quarry site is a massive granitic gneiss hills with thin overburden on both banks of a tributary joining with the Suib river at 500 m upstream of the damsite from the right bank. The transportation distance will be 1 to 2 km. Impervious material will be obtained from a gently sloping hill on the right bank at 1.8 km upstream of the damsite. Available volume will be 600 x 10^3 m^3 (see ANNEX M). Another 260 x 10^3 m^3 will be available on the left bank about 1 km upstream of the dam. Sand and gravel of 1.2 x 10^6 m^3 will be available in a deposit on the right bank between 0.5 km and 2.5 km upstream of the damsite. The area on the left bank 1.5 km downstream of the damsite will also provide 600 x 10^3 m^3 of sand and gravel.

A pre-feasibility design of the Bamseonggol dam and power station is shown in DRAWING Nos. 101 and 102. The active storage capacity of the reservoir is estimated to be 368 x 10^6 m^3 between HWS El. 305 m and LWS El. 264 m. A flood control space of 16 x 10^6 m^3 is provided in 1 m height above HWS. Two 12 m-dia. diversion tunnel will be excavated in a distance of 550 to 660 m in the left bank. A 105 m-high rockfill dam of 5.2 x 10^6 m^3 in volume will be constructed on the upper portion of weathered rock zone, with impervious core deeper in the same zone. An open chute spillway having a gated ogee crest will be located on the right bank. A 5 m-dia. headrace tunnel with a surge tank will be constructed in a length of 2,200 m in the left bank. A 210 m-long penstock-line will be laid on a ridge of granitic gneiss. The power station will be located on the left bank of the Suib river. The tail water surface will be at El. 184 m, which is 3 m higher than the HWS of the Hwacheon reservoir, due to topographic reason. The installed capacity will be 2 x 25 MW with 61.4 m^3/s of maximum discharge at 96.4 m of rated water head. The total construction cost will be \$ 125 x 10^6.

7.5 Inje Dam

The proposed Inje damsite is located in the northwest running gorge of the Naerin river, a tributary of the Soyang river.

An alternative site located 4 km downstream was omitted after a comparison of construction cost, though the geology was excellent. The riverbed is at El. 222.5 m which is 30.5 m higher than the high water surface El. 192 m of the Soyanggang reservoir.

The hydrological data estimated in the present study are;

Catchment area	:	1,043 km^2
Annual rainfall	:	1,200 mm
Annual inflow	:	857 x 10^6 m^3
Experienced maximum flood	:	5,000 m^3/s
2-year flood	:	900 m^3/s
50-year flood	:	5,400 m^3/s
200-year flood	:	7,500 m^3/s

A geological map of the damsite is shown in DRAWING No. 004. The river forms a rapid in the narrow valley of 30 to 40 m in width at the damsite. The valley walls on both banks are steep. The foot of left bank is a continuous rock outcrop and upper slope is covered with thin scree. The riverbed is covered with thin deposit of gravel. The right abutment is steep rocky mass with debris in shallow valleys. The rock is hard coarse grained granite having cracks on the surface. Boring DH 1 showed 1 m-deep soil and debris, 2.6 m-thick weathered rock. Seismic exploration result was interpreted that 3.5 km/s zone of 1 to 15 m in thickness below 1 to 5 m-thick overburden represents partially cracked rocks.

Two quarry sites are proposed on the right bank; one located on the left bank of a tributary 1.3 km upstream and the other located on the right bank of a tributary 1.5 km downstream of the damsite. Rocks in both sites are quite suitable for production of concrete aggregate. Impervious material deposits are few and located more than 5 km from the damsite. Sand and gravel deposits scattered between 5 to 8 km from the damsite together will make an available material of only 1×10^6 m^3 being in short of the requirement for the concrete dam construction.

A sample design of the Inje dam is shown in DRAWING No. 103. The active storage capacity of the reservoir will be 970×10^6 m^3 between HWS El. 344 m and LWS El. 300.6 m. A flood control space will be provided above HWS. A 9.8 m-dia. diversion tunnel will be excavated in a length of 440 m in the left bank. A 128 m-high concrete gravity dam will be constructed on the 3 km/s zone. The dam volume will be 1.7 $\times 10^6$ m^3. A gated spillway will be installed in the center section of the dam. A 7 m-dia. headrace tunnel will be constructed in the left bank mountains for 5.4 km to the west-northwest. The surge tank, penstock and powerhouse will be constructed on a ridge of granitic gneiss of which decomposed layer is estimated to be 20 m beside the Soyanggang reservoir, of which the high water surface is at El. 192 m. The tail water surface will be at El. 190 m. The installed capacity will be 2 x 61 MW with the maximum discharge of 114.7 m^3/s at the rated water head of 127.1 m. The total construction cost was estimated to be \$ 246 $\times 10^6$.

7.6 Hongcheon Dam

The proposed Hongcheon damsite is located in the north-northwesterly course of the Hong river 11 km upstream of the confluence of the north Han river and the Hong river. The social limitation of the reservoir water surface will be at El. 125 m above which Hongcheon town is located.

The hydrological data estimated in the present study are;

Catchment area	:	1,473 km^2
Annual rainfall	:	1,340 mm
Annual inflow	:	$1,351 \times 10^6$ m^3
Experienced maximum flood	:	7,100 m^3/s
2-year flood	:	1,900 m^3/s

50-year flood	:	6,800 m^3/s
200-year flood	:	9,000 m^3/s

A geological map of the damsite is shown in DRAWING No. 007. The rocks are quartzite, schists and their alternation. The riverbed is at about El. 49 m. The left abutment is a massive eastern slope of a north-northeast trending ridge. Quartzite is locally intercalated by schists. The slope is steep up to El. 100 m and gentler in higher portion. The 1 km/s zone is 4 to 10 m thick, 1.9 km/s zone is 5 to 12 m thick, 3.5 km/s zone is 5 to 12 m thick being underlain by 5.4 km/s zones. Two low velocity zones were recognized within 4.5 km/s zone. The riverbed. of schist formation is 120 m in width. A sand beach develops on the right side. The right abutment is a narrow ridge of schists trending north. Its top is at El. 170 m. The seismic wave velocity in the base rock was 4.3 to 4.7 km/s, 1 km/s zone was 1 to 6 m thick, 1.9 km/s zone was 2 to 12 m thick and 3.5 km/s zone was 3 to 8 m thick. Two fault lines were presumed. One is probably located along the foot of left bank between quartzite and schists. Another is assumed to pass the dam axis at El. 130 m on the left bank. They seem to be well compacted.

Quartzite hill located on the left bank about 2.5 km upstream of the site may be a quarry site but rocks are too hard and massive. A gneiss and schists hill located 3 km to the south-southeast of the damsite will provide appropriate rock material, but the transportation distance is rather long. Impervious material of more than 900 x 10^3 m^3 will be obtained from a terrace on the left bank between 1 km and 2 km upstream of the damsite. The material is clay loam and sandy loam of gneiss origin. Sand and gravel are abundant near the damsite.

A pre-feasibility design of the Hongcheon dam is shown in DRAWING No. 104. The active storage capacity of the reservoir will be 954 x 10^6 m^3 between HWS El. 120 m and LWS El. 93 m. A flood control space of 52 x 10^6 m^3 will be provided in 1 m height above HWS. A 12.2 m-dia. diversion tunnel will be excavated in a distance of 280 m in the right bank. A 80 m-high concrete dam with a volume of 830 x 10^3 m^3 will be constructed on the lower portion of weathered rock (1.9 km/s zone). A gated ogee spillway will be provided in the center section of the dam.

A powerhouse will be located adjacent to the spillway. The installed capacity will be 2 x 36.5 MW, utilizing a maximum discharge of 162.2 m^3/s and the rated water head of 53.5 m in the case of a constant draft operation. A valve house will be constructed instead of the powerhouse in the case of a variable draft operation. The maximum discharge capacity will be 109 m^3/s. The total construction cost will be \$ 170 x 10^6 for the constant draft operation and \$ 136 x 10^6 for the variable draft operation.

7.7 Gujeol Dam

The Gujeol damsite is located in the south-southwest running gorge of the Song river, a tributary of the south Han river. A limit of the maximum reservoir water surface will be El. 750 m above which the water surface will submerge the Seoul-Gangneung Highway.

The hydrological data estimated in the present study are;

Catchment area	:	101 km^2
Annual rainfall	:	1,186 mm
Annual inflow	:	79 x 10^6 m^3
Experienced maximum flood	:	450 m^3/s
2-year flood	:	80 m^3/s
50-year flood	:	600 m^3/s
200-year flood	:	900 m^3/s

A geological map of the Gujeol damsite is shown in DRAWING No. 008. The riverbed is at El. 691.3 m. The left bank slope is 30° up to El. 800 m and gentler therefrom. The riverbed is 30 m in width. The right bank is a wall with a slope of 45°. The rock is very hard sandstone. Scree deposits in the lower slope of left bank. There is a 2 km/s zone of seemingly cracky or weathered rock of 5 to 15 m in thickness under 0.3 to 1.4 km/s zone of 2 to 10 m in thickness. There is a low velocity zone at the foot of left bank.

A hill located on the left bank of a tributary on the left bank 300 m upstream of the damsite will be a quarry site. Impervious material of 700 x 10^3 m^3 will be available in the terrace located on the right bank 1.2 km upstream from the damsite. There are sand and gravel deposits in a reach of 3.5 to 5.5 km from the damsite, but the available volume is insufficient, being estimated to be 150 x 10^3 m^3.

The plan initially studied for the Gujeol dam is the herein called Songcheon plan in which about 350 m of water head is utilized for power generation by constructing a 14 km-long headrace tunnel between the damsite and the power station site in the Song river. This plan was later on superseded by the diversion plan which utilize 630 m of gross water head for power generation between the Gujeol damsite and the Namdae river on the east coast.

A sample design of the Gujeol dam (diversion plan) is shown in DRAWING No. 105. The reservoir active storage capacity will be 73.2 x 10^6 m^3 between HWS El. 748 m and LWS El. 723 m. A flood control space will be provided above HWS. A 7.8 m-dia. diversion tunnel will be excavated in a length of 450 m in the left bank. A 68 m-high rock-fill dam of 1.1 x 10^6 m^3 in volume will be constructed on the top of 2 km/s (weathered or cracky rock) zone with an impervious core resting in 2 km/s zone. An open chute spillway having a gated ogee crest will be constructed on the left bank.

An intake will be constructed in fresh and hard sandstone about 1.5 km north-northeast of the proposed Gujeol dam. A headrace tunnel will be constructed in a distance of 8 km toward east-northeast in the hill masses of sandstone, granite, slate and quartzite. Rocks are well cemented and little water seepage is expected. A surge tank and a 2,300 m-long penstock will be placed on a sharp edged steep ridge of quartzite, sandstone and slate. The power station will be located on the left bank of an irrigation reservoir of high water surface at El. 118 m and an active storage capacity of 3.7 x 10^6 m^3 in the Namdae river which drains to the Gangneung plain on the east coast. The installed capacity will be 2 x 29.5 MW with the maximum discharge of 11.5 m^3/s and the rated water head of 603.5 m. The total construction cost of the diversion plan was estimated to be \$ 83 x 10^6.

7.8 Dalcheon Dam

The Dalcheon damsite is located in the northeasterly course of the Dal river at 11 km upstream from the confluence of the south Han river and Dal river. The social limit of the reservoir maximum water surface will be at El. 117 m above which Goesan town is located.

The hydrological data estimated in the present study are;

Catchment area	:	1,348 km^2
Annual rainfall	:	1,106 mm
Annual inflow	:	932 x 10^6 m^3
Experienced maximum flood	:	3,700 m^3/s
2-year flood	:	1,500 m^3/s
50-year flood	:	4,900 m^3/s
200-year flood	:	6,400 m^3/s

A geological map of the Dalcheon damsite is shown in DRAWING No. 012. The riverbed is at El. 70 m. The rocks are granite and schist. The left abutment is a steep slope of granite partly weathered. Schist masses are irregularly distributed. The overburden is estimated to be less than 3 m in thickness. The riverbed is 100 m wide. Granite and schist is overlain by gravel deposit few meters thick. The right abutment is less steep with rather thick weathered material. Granite develops from the river side to El. 135 m, therefrom schist occurs. According to the results of seismic exploration, weathered zone is 5 m thick below overburden. Cracky rock is 2 to 15 m thick.

A quarry can be selected in the hard biotite-schist on the right bank 1.5 km upstream of the damsite. Impervious material is ample within 1.5 km from the damsite. The river deposit within 1.5 km from the damsite will provide 940 x 10^3 m^3 of sand and gravel.

A pre-feasibility design of the Dalcheon dam is shown in DRAWING No. 106. The reservoir active storage capacity will be 540 x 10^6 m^3 between HWS El. 117 m and LWS El. 101 m. A flood control space of 53 x 10^6 m^3 will be provided in 1 m above HWS. A 13 m-dia. diversion tunnel will be excavated in a length of 380 m in the left bank. A 57 m-high concrete gravity dam of 410 x 10^3 m^3 in volume will be constructed in the cracky rock zone. A gated ogee crest spillway will be provided in the center section of the dam. A valve house of 90.3 m^3/s in the maximum capacity will be constructed on the right side of the spillway. The total construction cost was estimated to be \$ 150 x 10^6.

7.9 Ganhyeon Dam

The Ganhyeon damsite is located in the south-southwest trending valley of the Seom river 26 km upstream of the confluence of the south Han river and Seom river. The social limitation of the reservoir maximum surface will be El. 115 m above which Weonju city is located.

The hydrological data estimated in the present study are;

Catchment area	:	1,180 km^2
Annual rainfall	:	1,349 mm
Annual inflow	:	945 x 10^6 m^3
Experienced maximum flood	:	5,400 m^3/s
2-year flood	:	1,400 m^3/s
50-year flood	:	5,800 m^3/s
200-year flood	:	7,800 m^3/s

A geological map of the Ganhyeon damsite is shown in DRAWING No. 013. Rock is green fine grained very hard quartz porphyry. The left abutment has a slope of 30° with a step at about El. 140 m. The flat riverbed of 100 m in width has many fresh rock outcrops. Gravel deposit is thin. The right abutment has a slope of 40°. Rocks are sound.

Fresh hard granite and quartz porphyry with medium-space cracks located on the right bank of the tributary joining with the Seom river from the right at 500 m downstream of the damsite will provide quarry material. The decomposed granite located between 0.5 km and 1.5 km across a saddle to the southeast will be an ample source of impervious material. A terrace located on the right bank between 0.5 km and 1.2 km is a thick sand and gravel deposit. Available quantity is estimated to be 870 x 10^3 m^3.

A pre-feasibility design of the Ganhyeon dam is shown in DRAWING No. 107. The reservoir storage capacity will be 540 x 10^6 m^3 between HWS El. 111.4 m and LWS El. 91 m. A flood control space of 92 x 10^6 m^3 will be provided in the 2 m height above HWS. A 5.3 m dia. diversion tunnel will be excavated in a length of 280 m in the left bank. A 50 m-high concrete gravity dam of 180 x 10^3 m^3 in volume will be constructed with a gated ogee crest spillway. A valve house of 89.1 m^3/s in the maximum discharge capacity will be constructed on the left side of the spillway. The total construction cost was estimated to be \$ 95 x 10^6.

7.10 Bonghwa Dam

The Bonghwa damsite is located in a south-southeast running course of the Nagdong river 26 km north-northeast of the Andong dam. The high water surface of the Andong reservoir at El. 160 m stretches to 13 km downstream of the Bonghwa damsite. An alternative damsite located 3 km upstream of the proposed damsite was given up, because thick debris, slumping rock blocks and intensely cracked outcrops on the steep right bank slope implied a landslide.

The hydrological data estimated in the present study are;

Catchment area	:	1,135 km^2
Annual rainfall	:	1,033 mm
Annual inflow	:	695 x 10^6 m^3
Experienced maximum flood	:	3,800 m^3/s
2-year flood	:	1,000 m^3/s
50-year flood	:	4,400 m^3/s
200-year flood	:	5,900 m^3/s

A geological map of the Bonghwa damsite is shown in DRAWING No. 015. The riverbed is at El. 178 m. The rocks are the alternation of well cemented sandstone, conglomerate and slate. There are two minor faults across the river. The left abutment is deposited by talus of 5 m in thickness including tumbling blocks up to El. 250 m with a slope of 35°. Higher portion is a steep cliff. Cracky zone beneath the deposit is estimated to be 6 to 12 m in thickness. The river is 50 m in width.

Gravel deposit is 1 to 2 m thick. The cracky zone will be 5 m in thickness. The right abutment is a steep slope up to El. 250 m and therefrom gentle. Under soil and talus deposit, the weathered zone will be 5 m thick. The thickness of cracky rock increases from 5 m to 20 m toward higher portion. The topography will limit the reservoir maximum water surface at El. 301 m.

Good rock material of well cemented sandstone and conglomerate will be obtained in hills on the left bank 0.5 km upstream and 1.5 km upstream from the damsite but with rather difficult access. Impervious material will not be enough in case of a rockfill dam. Sand and gravel deposit within 11 km from the damsite will provide 140 x 10^3 m^3.

A sample design of the Bonghwa dam is shown in DRAWING Nos. 108 and 109. The reservoir active storage capacity will be 681 x 10^6 m^3 between HWS El. 297 m and LWS El. 259 m. A flood control space will be provided above HWS. A 10 m-dia. diversion tunnel will be excavated in a length of 410 m in the left bank. A 129 m-high concrete gravity dam of 1.7 x 10^6 m^3 in volume having a gated ogee crest center spillway will be constructed. The right wing of the dam will stretch upstream along the crest of a ridge. An intake will be constructed on the right bank 500 m upstream from the dam. A 1.8 km-long headrace tunnel will be constructed in the right bank. The power station will be located 2 km downstream of the damsite. The surge tank, penstock and powerhouse will be constructed on a steep and stable ridge of well cemented sandstone. The tailwater surface will be at El. 173.2 m. The installed capacity will be 2 x 36 MW with the maximum discharge of 83.5 m^3/s and the rated water head of 102.6 m. The total construction cost was estimated to be \$ 200 x 10^6.

7.11 Imha Dam

The Imha damsite is located in the southwesterly course of the Banbyeon river 26 km upstream of the confluence of the Nagdong river and the Banbyeon river.

The hydrological data estimated in the present study are;

Catchment area	:	1,230 km^2
Annual rainfall	:	995 mm
Annual inflow	:	725 x 10^6 m^3
Experienced maximum flood	:	2,700 m^3/s
2-year flood	:	1,100 m^3/s
50-year flood	:	3,500 m^3/s
200-year flood	:	4,500 m^3/s

A geological map of the Imha damsite is shown in DRAWING No. 016. The riverbed is at El. 113 m. The rock is granite, which crops out in the riverbed and foot slope of both banks. Middle and upper part of the slopes are overlain by decomposed granite, of which thickness is estimated to be 20 m on the left bank and 5 m on the right bank. The riverbed of 50 m in width is rocky floor with no conspicuous sheared zone. Gravel deposits in places. The results of boring and seismic exploration were suggestive a presence of a sheared zone across the bore hole DH 1. The topography will limit the reservoir maximum water surface at El. 195 m.

Promising quarry sites will be rather cracky quartzite on the left bank 1.4 km upstream of the damsite and quartzite, sandstone and intruded diorite located on the right bank 2 km upstream of the damsite. Earth materials of granite, diorite and quartzite origin are obtainable within 5.5 km reach of the damsite. Sand and gravel deposit between immediately upstream and 6 km upstream of the damsite is estimated to be 950 x 10^3 m^3.

A pre-feasibility design of the Imha dam for the constant draft operation is shown in DRAWING Nos. 110 and 111. The reservoir active storage capacity will be 920 x 10^6 m^3 between HWS El. 192 m and LWS El. 158 m. A flood control space of 100 x 10^6 m^3 will be provided in the height of 2 m above HWS. An 11 m-dia. diversion tunnel will be excavated in a length of 460 m in the left bank. An 87 m-high concrete gravity dam of 728 x 10^3 m^3 in volume will be constructed with a gated ogee crest spillway in the center section of the dam. A powerhouse will be located on the right side of the spillway. The tailwater surface will be at El. 112.9 m. The installed capacity will be 2 x 24 MW with the maximum discharge of 92.6 m^3/s at a rated water head of 61.2 m. A gated concrete re-regulation dam will be constructed on the granite base 6 km downstream of the dam. The total construction cost was estimated to be \$ 155 x 10^6.

A pre-feasibility design of the Imha dam for the variable draft operation is shown in DRAWING No. 112. The reservoir active storage capacity will be 583 x 10^6 m^3 between HWS El. 185 m and LWS El. 158 m. A flood control space of 114 x 10^6 m^3 will be provided in the height of 3 m above HWS. The dam will be 81 m in height and 610 x 10^3 m^3 in volume.

A valve house of 26.8 m^3/s in the maximum capacity will be constructed instead of the powerhouse and the re-regulation dam will not be necessary in the case of a variable draft operation. The total construction cost was estimated to be \$ 113 x 10^6.

7.12 Hamyang Dam

The Hamyang damsite is located in the southeasterly course of the Mansu river, a tributary of Imcheon river, about 20 km upstream of the confluence of the Nam river and Imcheon river. It is approximately on the boundary between Jeonla-bug Do and Gyeongsang-nam Do.

The hydrological data estimated in the present study are;

Catchment area	:	264 km^2
Annual rainfall	:	1,422 mm
Annual inflow	:	276 x 10^6 m^3
Experienced maximum flood	:	1,850 m^3/s
2-year flood	:	300 m^3/s
50-year flood	:	2,050 m^3/s
200-year flood	:	2,800 m^3/s

A geological map of the Hamyang damsite is shown in DRAWING No. 017. The riverbed is at El. 304.8 m. The damsite is formed of diorite.

The left bank slope is covered with soil and partly slumping blocks for 2 to 3 m in thickness. Lower part is a steep slope of exposed rock. The riverbed of 70 m in width has outcrops which in place show open joints. The right abutment is a very steep slope with slumping blocks and intensely weathered rock in a thickness of 5 m. The thickness of cracky zone below the overburden is estimated to be 7 to 20 m in the left abutment, very small in the riverbed and 3 to 12 m in the right abutment.

A diorite hill located on the left bank 700 m downstream of the damsite will be a quarry site. Impervious material of 880 x 10^3 m^3 will be available from the weathered diorite immediately upstream of the damsite and weathered granite 3 km upstream of the damsite, both on the left bank. Sand and gravel available will be only 150 x 10^3 m^3.

A sample design for the Hamyang dam revised after the draft Final Report is presented in DRAWING Nos. 116 and 117 in ADDENDUM (these supersede DRAWING No. 113). The reservoir active storage capacity will be 251 x 10^6 m^3 between HWS El. 392 m and LWS El. 339 m. A flood control space of 8 x 10^6 m^3 will be provided in 1 m height above HWS. A 12 m-dia. diversion tunnel will be excavated in a length of 730 m on the left bank. A 94 m-high rockfill dam of 4.38 x 10^6 m^3 in volume will be constructed on part of slumping blocks and intensely weathered rock zone with impervious core on the lower part of cracky rock zone. A gated open chute spillway will be located on the left bank. An intake will be located 400 m upstream of the dam axis on the left bank. A headrace tunnel of 2.0 m in diameter will be constructed for a distance of 8.4 km on the left bank through diorite, granite gneiss and granite. The power station will be located in the Imcheon river 13 km downstream of the damsite. The penstock and surge tank will be placed on a narrow ridge of granite which is intensively weathered in the upper portion. The tailwater surface will be at El. 162.1 m. The installed capacity will be 1 x 13 MW with the maximum discharge of 9.3 m^3/s and the rated water head of 161.1 m. The total construction cost will be \$ 110 x 10^6.