

JAPAN INTERNATIONAL COOPERATION AGENCY
THE MINISTRY OF INDUSTRY, MINES AND ENERGY
THE ROYAL GOVERNMENT OF CAMBODIA

THE STUDY ON
WATER SUPPLY SYSTEM
FOR SIEM REAP REGION
IN CAMBODIA

FINAL REPORT
Vol. II MAIN REPORT

JUNE 2000

NIPPON KOEI CO., LTD.

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LIST OF REPORTS

Vol. I	EXECUTIVE SUMMARY
Vol. II	MAIN REPORT
Vol. III	SUPPORTING REPORT
Vol. IV	DATA BOOK

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(as of June 1999)

PREFACE

In response to a request from the Royal Government of Cambodia, the Government of Japan decided to conduct the Study on Water Supply System for Siem Reap Region in Cambodia and entrusted the Study to the Japan International Cooperation Agency (JICA).

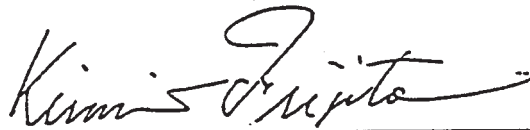
JICA selected and dispatched a Study Team headed by Mr. Osamu TAKAHASHI, joint venture of Japanese consulting firms of Nippon Koei Co., Ltd. and Nippon Suido Consultants Co., Ltd. to the Kingdom of Cambodia, six times between December 1996 to June 2000. In addition, JICA set up an advisory committee headed by Ms. Keiko Yamamoto, Institute for International Cooperation JICA, between December 1996 and June 2000, which examined the Study from specialist and technical points of view.

The Study Team held discussions with the officials concerned of the Royal Government of Cambodia, and conducted field surveys at the Study area. Upon returning to Japan, the Study Team conducted further studies and prepared the final report.

I hope that this report will contribute to the promotion of the Project and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Royal Government of Cambodia for their close cooperation extended to the Study Team.

June, 2000



Kimio Fujita
President

Japan International Cooperation Agency

June, 2000

Mr. Kimio Fujita
President
Japan International Cooperation Agency
Tokyo, Japan

Dear Sir,

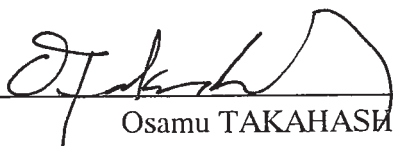
LETTER OF TRANSMITTAL

It is with great pleasure that we submit to you the Final Report of the Study on Water Supply System for Siem Reap Region in Cambodia completed by the Study Team with cooperative efforts of the Ministry of Industry, Mine and Energy (MIME) and other parties concerned. The report has been prepared for the Royal Government of Cambodia in implementing the effective water supply system project for Siem Reap Region in Cambodia.

The report consists of four volumes of the Executive Summary, Main Report, Supporting Report, and the Data Book. The Executive Summary presents the outline of the study results and the Main Report gives all the study results regarding the plan for water supply system. The Supporting Report describes more detail results with data for the Study. The Data Book compiles useful reference data relevant to the Study.

Taking this opportunity, on behalf of the Study Team, I would like to express my heartfelt gratitude to the personnel from JICA, Advisory Committee, Ministry of Foreign Affairs, Ministry of Health and Welfare, Embassy of Japan in Cambodia and JICA Phnom Penh Office and Cambodian officials from Steering Committee comprised of relevant government agencies who extended their kind assistance and cooperation for the entire study period to the Study Team. The Study Team hopes that the results of this Study contribute to the future implementation of the water supply project in Siem Reap Region in Cambodia.

Yours faithfully,



Osamu TAKAHASHI

Team Leader

The Study on Water Supply System
for Siem Reap Region
in Cambodia



LEGEND

	Capital
	Capital of Province
	National Road
	National Boundaries
	Provincial Boundaries
	Railway

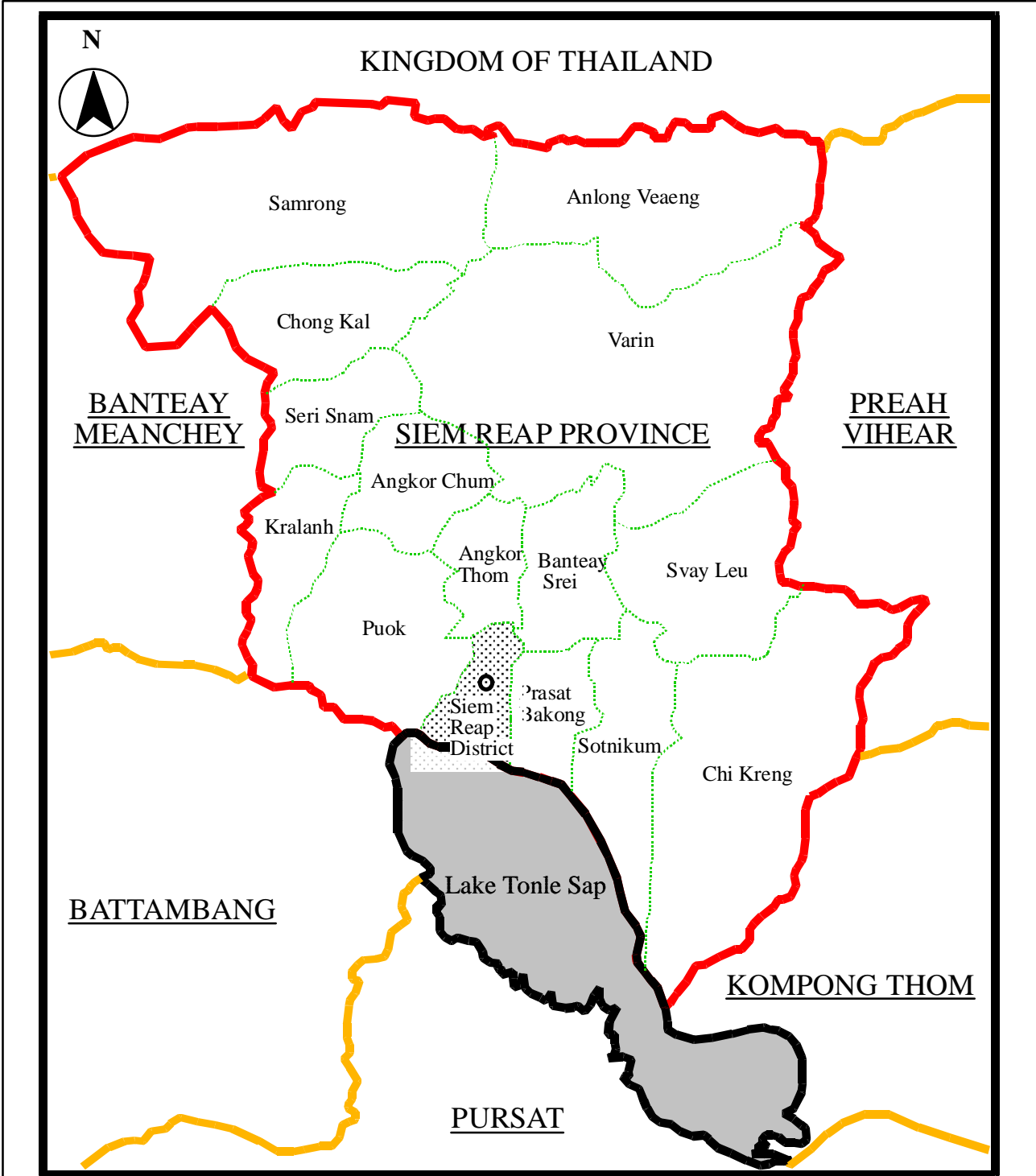


KEY MAP

The Study on Water Supply System for Siem Reap Region in Cambodia

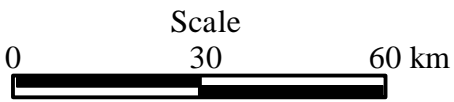
Location Map of Cambodia

Japan International Cooperation Agency



Legend

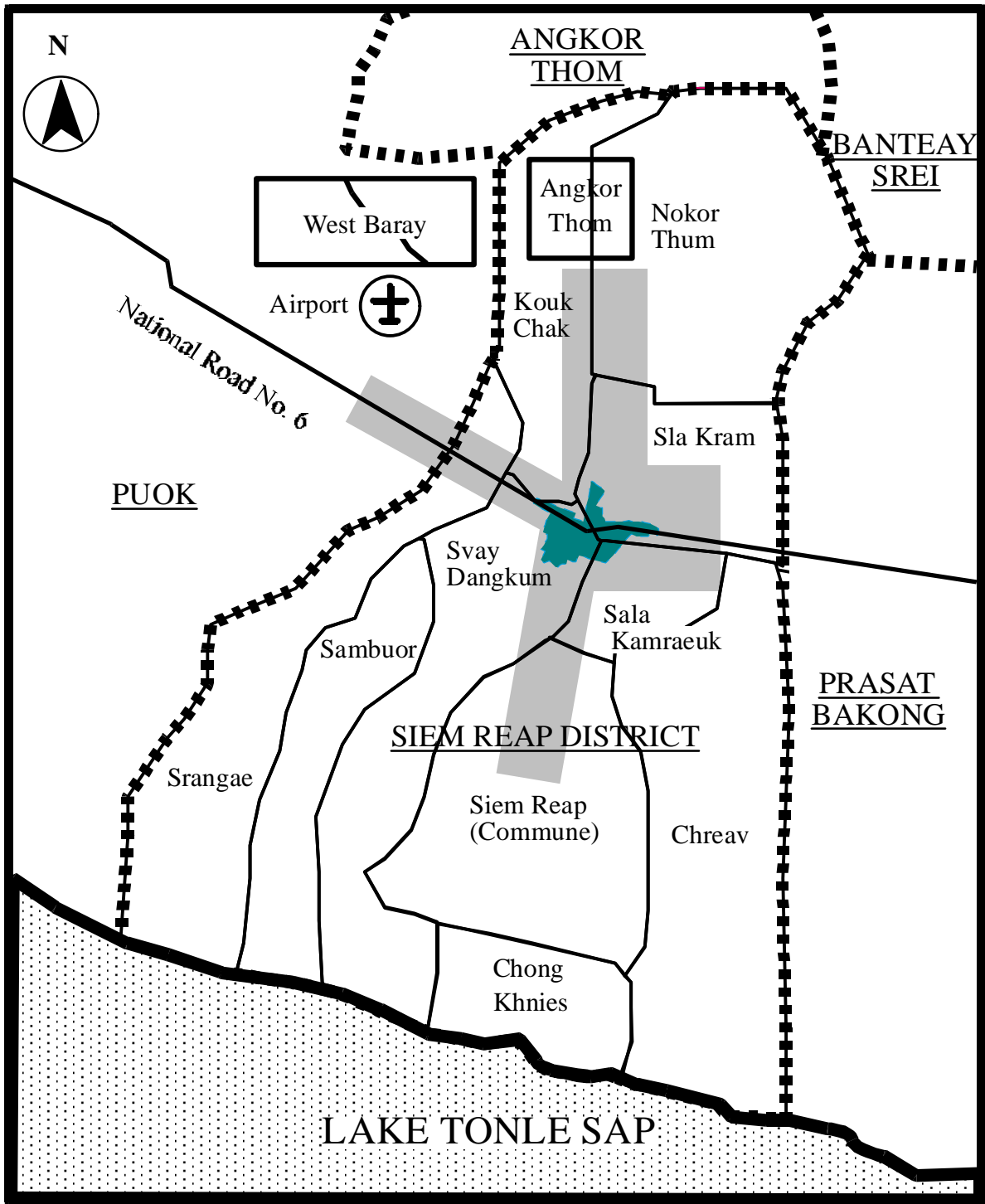
<u>PURSAT</u>	: Province Name
Svay Leu	: District Name
	: Provincial Boundaries
	: District Boundaries
	: Siem Reap Town



**The Study on Water Supply System
for Siem Reap Region in Cambodia**

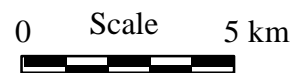
**Location Map of Siem Reap Province
with District Names**

Japan International Cooperation Agency



Legend

<u>SIEM REAP</u> : District Name	— : Commune Boundaries
Sla Kram: Commune Name	■ : Social Survey Area
■■■■■ : District Boundaries	■ : Water Supply Service Area



**The Study on Water Supply System
for Siem Reap Region in Cambodia**

**Location Map of Study Area
with Commune Names**

Japan International Cooperation Agency

**THE STUDY ON WATER SUPPLY SYSTEM
FOR SIEM REAP REGION IN CAMBODIA**

**FINAL REPORT
Vol. II MAIN REPORT**

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ABBREVIATIONS

ACP	Asbestos Cement Pipe
ADB	Asian Development Bank
AFD	French Agency for Development
AIDS	Acquired Immune Deficiency Syndrome
APSARA	Authority for the Protection of the Site and the Management of Angkor Region
ASEAN	Association of Southeast Asian Nations
B/C	Benefit-Cost Ratio
BOD	Biochemical Oxygen Demand
CARERE	Cambodian Area Rehabilitation And Re-generation
CAD	Computer Aided Design
CFD	Caisse Francaise de Developpement (French Development Bank)
COD	Chemical Oxygen Demand
CPA	Complementary Package of Activities
CPI	Consumer Price Index
CRF	Capital Recovery Factor
D	Depth
DDT	Dichlorodiphenyl Trichloroethane
Dept.	Department
DFID	Department For International Development, UK
DIP	Ductile cast Iron Pipe
Div.	Division
DO	Dissolved Oxygen
DSR	Debt Service Ratio
DWL	Dynamic Water Level
EC	Electric Conductivity
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EL	Elevation Level
EU	European Union
FAO	Food and Agriculture Organization
FBC	Feed Back Committee

FIRR	Financial Internal Rate of Return
F/S	Feasibility Study
GAD	Gender and Development
GAMS	General Algebraic Modeling System
GDP	Gross Domestic Product
GIS	Geographic Information System
GL	Ground Level
GOJ	Government of Japan
GWL	Ground Water Level
GVA	Gross Value Added
H	Height
HCMC	Health Center Management Committee
HWL	High Water Level
ICP	Inductively Coupled Plasma
ID	Inner Diameter
IDA	International Development Association (The World Bank Group)
IEE	Initial Environment Examinations
IO	International Organizations
IPM	Integrated Pest Management
ISO	International Standards Organization
It/R	Interim Report
IWDA	International Women's Development Agency
JICA	Japan International Cooperation Agency
JIS	Japanese Industrial Standard
JWWA	Japan Waterworks Association
L	Length
LAN	Local Area Network
LDC	Least Developed Countries
LPG	Liquefied Petroleum Gas
L.S.	Lump Sum
LWL	Low Water Level
M	Meter
MDS	Meter District System
MIME	Ministry of Industry, Mines and Energy

MOA	Ministry of Agriculture, Forest and Fisheries
MOEF	Ministry of Economy and Finance
MOH	Ministry of Health
MOP	Ministry of Planning
MOT	Ministry of Tourism
M/P	Master Plan
MPA	Minimum Package of Activities
MPN	Most Probable Number
MSL	Mean Sea Level
N.D	Not Detected
NGO	Non-government Organization
NPV	Net Present Value
NTU	Nephelometric Turbidity Unit
O&M	Operation and Maintenance
OD	Outer Diameter
ODA	Official Development Assistance
PBML	Provincial Budget Management Law
PDIME	Provincial Department of Industry, Mines and Energy
PE	Poly Ethylene pipe
PPWSA	Phnom Penh Water Supply Authority
PSP	Private Sector Participation
PVC	Poly Vinyl Chloride (pipe)
Q	Quantity, Flow
RC	Reinforced Concrete
RGC	Royal Government of Cambodia
SCNC	Supreme Council for Natural Culture
S/O	Simulation and Optimization
SP	Steel Pipe
SS	Suspended Solid
SWL	Static Water Level
TCU	True Color Unit
TDS	Total Dissolved Solid
THM	Trihalomethane
UFW	Unaccounted For Water

UK	United Kingdom
UNDP	United Nations Development Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFPA	United Nations Population Fund
UNICEF	United Nations Children Fund
UNO	United Nations Organization
UNTAC	United Nations Transition Authority for Cambodia
UNV	United Nations Volunteer
USA	United States of America
US\$	US Dollar
VIP	Ventilated Improved Pit
VLf	Very Low Frequency
W	Width
WAC	Women's Association of Cambodia
WB	World Bank
WES	Water and Environmental Sanitation
WFP	World Food Program
WHO	World Health Organization
WID	Women In Development
ZEMP	Zoning and Environment Management Plan (prepared by UNESCO)
	Diameter

MEASUREMENT UNITS

Extent

cm ²	=	Square centimeters (1.0 cm x 1.0 cm)
m ²	=	Square meters (1.0 m x 1.0 m)
km ²	=	Square kilometers (1.0 km x 1.0 km)
ha	=	Hectares (10,000 m ²)

Volume

cm ³	=	Cubic centimeters (1.0 cm x 1.0 cm x 1.0 cm)
m ³	=	Cubic meters (1.0 m x 1.0 m x 1.0 m)
m ³ /day	=	Cubic meters per day
m ³ /h	=	Cubic meters per hour
m ³ /min	=	Cubic meters per minute
m ³ /s	=	Cubic meters per second
l or lit	=	Liter (1,000 cm ³)
lpcd	=	Liter per capita per day

Length

mm	=	Millimeters
cm	=	Centimeters (cm = 10 mm)
m	=	Meters (m = 100 cm)
km	=	Kilometers (km = 1,000 m)

Weight

g	=	Grams
mg	=	Milligrams (1/1,000 g)
mg/l	=	Milligrams per liter
μ g/l	=	Micrograms per liter
kg	=	Kilograms (1,000 g)
kg/cm ²	=	Kilograms per square centimeter
t	=	Metric ton (1,000 kg)

Currency

US\$	=	United State Dollars
		US\$1.0 = J¥120 = R 3,800
J¥	=	Japanese Yen
R	=	Cambodian Riels

Time

s	=	Seconds
min.	=	Minutes (60 s)
h	=	Hours (60 min.)

Energy

kVA	=	Kilovolt Ampere
kW	=	Kilowatt

Others

per/km ²	=	Persons per square kilometer
S/m	=	Siemens per meter
μ S/m	=	Micro siemens per meter

CHAPTER 1 INTRODUCTION

1.1 Background of the Study

The Kingdom of Cambodia occupies 181,035 km² in the Indo-China Peninsular and is bordered by three countries, Thailand, Lao PDR, and Vietnam. The total population of the country was 11.43 million in 1998. Due to a long spell of civil unrest, the society and economy in the country have been damaged heavily. While the situation has improved gradually in the last decade, GDP (Gross Domestic Product) per capita of the country was only US\$ 286 in 1998 (Socioeconomic Development Requirements and Proposals, January 1999), which is still one of the lowest levels in the world. The restoration of deteriorated infrastructures is considered as the most urgent need in the country.

Siem Reap is one of Cambodia's 24 provinces and is located in the northern part of the country. The total area of the province is 10,299 km² with a population of 695,485 in 1998. The total population of the Siem Reap District was 103,752 in 1998. Out of which, female population comprises 53,563 (51.63% of the total). Over 90% of the population is ethnic Khmer, who are basically Theravada Buddhists.

The Siem Reap Town is located 5 km south of the Angkor heritage that is well known as one of the important historical heritages in the world. These temples were constructed by Khmer Imperials between the 7th and 15th centuries. The Angkor heritage is also recognized as a big potential resource for the tourism development of this area. The Royal Government of Cambodia (RGC) encourages recovery and development of the town with the financial and technical help from donor countries. However, the infrastructure in the town area has not been sufficiently improved yet. In this regard, the RGC requested the Government of Japan (GOJ) to carry out a study on 'Integrated Plan for Angkor and Siem Reap Region' in February 1993. The GOJ decided to carry out the study, and the scope of work was agreed between the Japanese and Cambodian sides in March 1994. However, the study was postponed in July 1995 due to unrest and security conditions in the objective study area.

In January 1996, the GOJ dispatched a mission to determine what infrastructures in the region most urgently needed to be developed. As a result, the mission concluded that the development of water supply system is the most urgent need in Siem Reap Region.

In response to the official request of the RGC, the GOJ dispatched the Japan International Cooperation Agency (JICA) preparatory study team to Cambodia to discuss the scope of work for a study on 'Water Supply System for Siem Reap Region in Cambodia' (the Study). Both parties discussed the scope of work and

finally reached an agreement, and it was presented in the Minutes of Meeting signed on September 26, 1996 in Phnom Penh, Cambodia.

On the basis of the scope of work concluded, JICA made a contract with the joint venture of Japanese consulting firms of Nippon Koei Co., Ltd. and Nihon Suido Consultants Co., Ltd. in December 1996 to carry out the Study. The JICA Study Team, which is organized by experts of the joint venture consultants, was dispatched to Cambodia on December 16, 1996 to commence the fieldwork. Subsequently, the JICA Study Team worked for the Study as follows:

- From December 7, 1996 to December 15, 1996 for the preparatory work in Japan,
- From December 17, 1996 to July 15, 1997 for the 1st fieldwork in Cambodia,
- From July 16, 1997 to July 31, 1997 for the 1st homework in Japan,
- From February 5, 1998 to March 21, 1998 for the 2nd fieldwork,
- From December 1, 1998 to February 13, 1999 for the 3rd fieldwork,
- From January to the end of March, 1999 for the 2nd homework,
- From May 13, 1999 to August 31, 1999 for the 4th fieldwork,
- From August to the end of September 1999 for the 3rd homework, and
- From October to the end of November 1999 for the 5th fieldwork.
- From January 2000 to the middle of February 2000 for the 4th homework.
- From March 10, 2000 to March 24 2000 for the 6th fieldwork.
- From the middle of May 2000 for 3 weeks for the 5th homework

1.2 Objectives of the Study

The objectives of the Study are categorized in the following four items:

- 1) To evaluate potential of water sources for the water supply system in Siem Reap Region.
- 2) To formulate a Master Plan for the water supply system in the Siem Reap Town.
- 3) To conduct a Feasibility Study on priority project identified in the Master Plan.
- 4) To pursue technology transfer to counterpart personnel in the course of the Study.

1.3 Actual Execution of the Study

The Study is divided into three major phases. These are,

- Phase I : Study on Water Resources,
- Phase II : Preparation of Master Plan, and
- Phase III : Preparation of Feasibility Study.

Phase I consisted of thorough investigation of four probable alternative water sources, namely, groundwater, West Baray, Siem Reap River, and Lake Tonle Sap.

Starting with aerial photo interpretation and site reconnaissance, this phase included extensive topographic survey, well inventory survey, water quality analysis, electrical sounding, core drilling and pumping tests for hydrogeological investigations, geophysical logging and soil tests, hydrological investigations including water balance study, and computer simulation study for groundwater development and land subsidence.

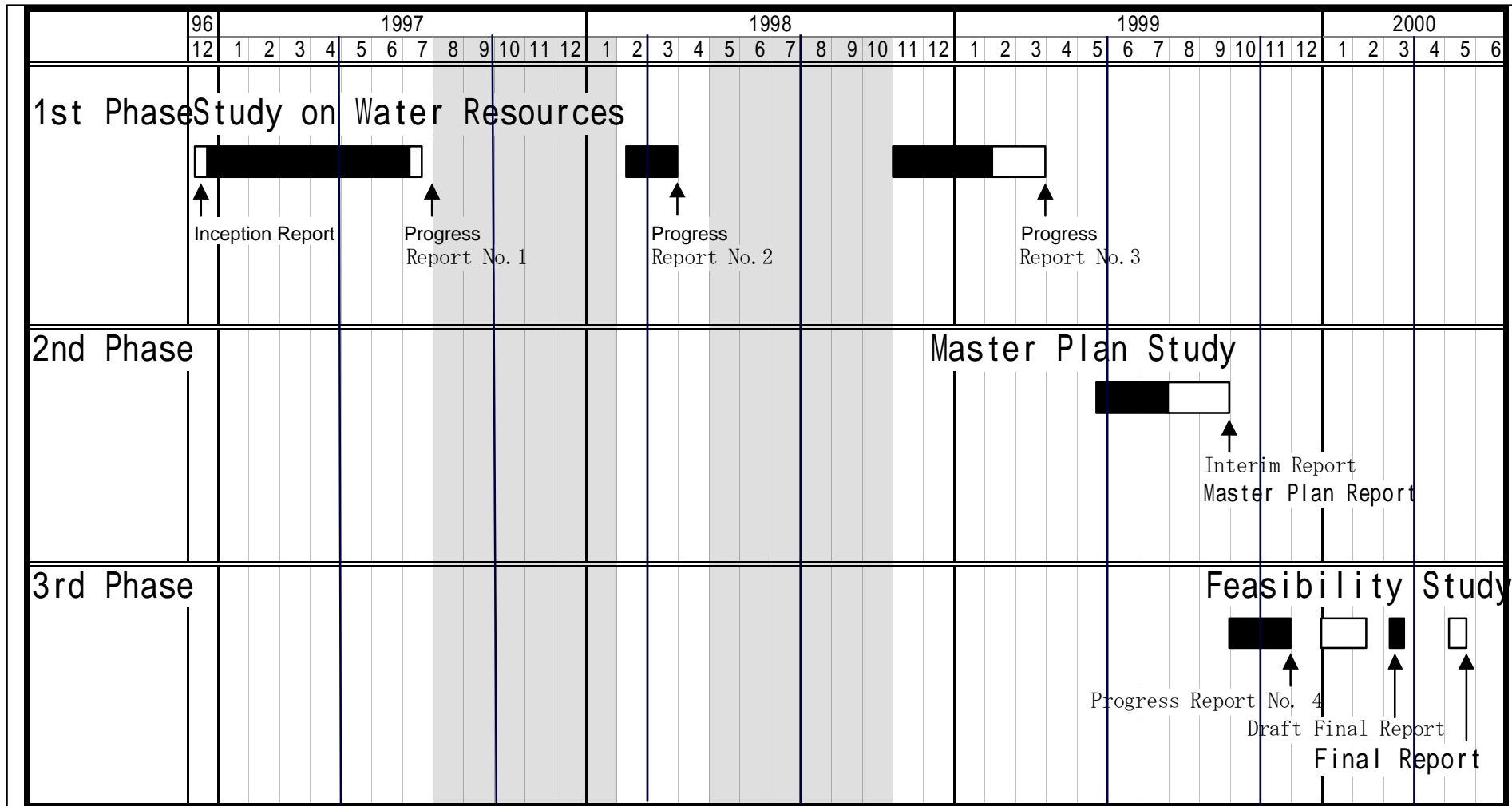
This Phase also included various social and environmental investigations. These covered review of city planning and tourism planning, environmental investigation in both dry and wet seasons, public awareness and water use survey, and study on social relations.

The target of Phase II was to prepare a Master Plan for water supply system in Siem Reap Region up to the year 2010. The work started with water demand projection and preliminary plan for water resources development for four possible alternative sources. The Study recommended the most suitable option for the target year 2010 based on various factors. The Master Plan also included preliminary plans for water supply system, operation and maintenance, institution and organization, cost estimate and financial plan. With careful evaluation of all aspects, a priority project was selected. The Master Plan was rounded up with Initial Environmental Examination (IEE) and future wastewater disposal plan. The Master Plan was presented in the Interim IT/R.

The Study Team explained the Master Plan to the Steering Committee, which is represented by all concerning ministries and agencies of RGC. In that meeting, the Steering Committee agreed with the Master Plan as presented in the IT/R. The Steering Committee confirmed that the water source up to the year 2010 would be groundwater. The Steering Committee also confirmed the priority project for the first stage development as defined in the IT/R.

Phase III concentrated on the priority project identified in the Master Plan. With the help of additional, a Feasibility Study was prepared for the priority project that covers preliminary facilities design, construction plan, financial plan and organizational plan. An Environmental Impact Assessment (EIA) was also carried out to assess any impacts due to project implementation. After making economic, financial, organizational, technical, social, and environmental evaluation, an implementation program for the priority project was prepared.

According to the original schedule, the Study was expected to be completed by July 1999. However, due to unforeseen political and social disorder that prevailed in Cambodia, the Study was suspended two times for a total period of 11 months. The schedule of the Study is shown in Figure 1.3.1.



Work in Cambodia
 Homework in Japan

<p>The Study on Water Supply System for Siem Reap Region in Cambodia</p>
<p>Japan International Cooperation Agency</p>

Figure 1.3.1
The Study Schedule

1.4 Organization of the Study

1.4.1 Japanese Organization

The Japanese organization consists of the Study Team under JICA direction and the Advisory Committee set up at the JICA Headquarters.

Study Team

- | | |
|--|--|
| 1. Mr. Osamu TAKAHASHI /
Mr. Kiyohiro INOUE | Team Leader / Water Supply Planner |
| 2. Mr. Tadao SUZUMURA | Hydrogeologist / Geotechnical Engineer |
| 3. Mr. Yasuhiko KATO /
Dr. John P. Jolly | Hydrologist / Water Quality Expert |
| 4. Mr. Tadashi NAKAYU | Geophysics Expert |
| 5. Mr. Yoshinao MIURA | Drilling Expert |
| 6. Mr. Ryosuke ITO | Topographic Survey Expert |
| 7. Mr. Shu TAKAHASHI /
Mr. Masahiro TAHAKASHI | Groundwater and Land Subsidence
Simulation Expert |
| 8. Mr. Takemasa MAMIYA | Water Supply Facilities Planner |
| 9. Mr. Hiroshi MACHIDA | Water Supply Management Expert |
| 10. Dr. Jun LIU /
Mr. Motoo YANAI | Construction Planner / Cost Estimator |
| 11. Mr. Tatsuo TASHINO | Economic and Financial Expert |
| 12. Dr. A.K.M. Nurul ISLAM | Environment and Social Expert |
| 13. Mr. Shigenobu HIBINO /
Ms. Tomoshi ICHIKAWA | Coordinator |

Duplicate names for some position indicate replacement.

JICA Advisory Committee

- | | |
|--------------------|-------------|
| Ms. Keiko YAMAMOTO | Chairperson |
| Mr. Masaki ITOH | Member |

1.4.2 Cambodian Organization

The Cambodian counterpart agency for the Study is the Ministry of Industry, Mines and Energy (MIME). The Cambodian organization for the Study consists of counterpart staffs from MIME and a Steering Committee formed by MIME incorporating members from all concerned Ministries and Agencies.

Steering Committee

1.	H.E. Vann Molyvann	President Director General of APSARA Authority	Advisor
2.	H.E. Phork Sovanrith	Under Secretary of State, MIME	Chairman
3.	H.E. Suy San	Deputy Governor, Siem Reap Province	Deputy Chairman
4.	Ms. Tep Vattho	Chief of APSARA in Siem Reap	Deputy Chairman
5.	Mr. Peng Navuth	Director, Urban Water Supply Department, MIME	Member
6.	Mr. Son Suklin	Chief of Service, Department of Public Works and Transport, Siem Reap	Member
7.	Mr. Phiv Phalkun	Chief Officer, Ministry of Water Resources and Meteorology	Member
8.	Mr. Tat Bunchhoeun	Dept. of Agriculture, Forestry and Fisheries	Member
9.	Mr. Chiv Hur	Director, MIME, Siem Reap	Member
10.	Mr. Chan Sengla	Deputy Director, Siem Reap Water Works	Member
11.	Mr. Yin Sobin	Officer, Urban Water Supply Dept., MIME	Member
12.	Mr. Cheav Channy	Officer, Urban Water Supply Dept., MIME	Member

Counterpart Staff

A number of counterpart staffs worked in the Study for certain time in different stages. Some of them are from MIME and some of them are from Provincial Department of Industry, Mines and Energy (PDIME) at Siem Reap.

1.	Mr. Ken Vath	MIME, Phnom Penh
2.	Mr. Peng navuth	MIME, Phnom Penh
3.	Mr. Ke Chhan	PDIME, Siem Reap
4.	Mr. Chum Saren	PDIME, Siem Reap
5.	Mr. Chiv Hur	PDIME, Siem Reap
6.	Mr. Thlauk Sina	PDIME, Siem Reap
7.	Mr. Chan Sengla	PDIME, Siem Reap
8.	Mr. Moni Rath	PDIME, Siem Reap
9.	Mr. Sam Sauy	PDIME, Siem Reap
10.	Mr. Yin Sobin	MIME, Phnom Penh
11.	Mr. Cheav Channy	MIME, Phnom Penh

CHAPTER 2 THE STUDY AREA

2.1 Definition of the Study Area

The Study area covers the Siem Reap Town and parts of the Lake Tonle Sap, the West Baray (Reservoir) and Siem Reap River Basin. All physical investigations covered the entire Study area. ‘Public Awareness and Water Use Survey’ conducted by the Study Team covered an area comprising the town center and surroundings. The service area proposed in the Master Plan is, however, smaller than the social survey area.

2.2 Natural Conditions

Cambodia has a vast central plain surrounded on three sides by highlands except the southern side. This plain is divided by the Mekong and Bassac Rivers, both of which flow in a southeast direction and enter into the South China Sea through the Mekong Delta in Vietnam. The Tonle Sap River originating from the Lake Tonle Sap joins the Mekong River in Phnom Penh, the capital city of Cambodia. The lake is located about 100 km northwest of Phnom Penh, and has a particular hydrological characteristic that the flow of the Mekong River reverses direction during the wet season. The Siem Reap Town is located on a lake terrace formed by fan deposits about 15 km north from the shore of the lake. The town is 314 km from Phnom Penh by road. However, direct distance is around 200 km.

The climate of Cambodia is classified as ‘Tropical Monsoon’ with definite wet and dry seasons affected by the direction of monsoon. The southwest monsoon prevails in the wet season from May to October. Air temperature is highest in April and lowest in December. In Siem Reap Town, the average monthly air temperature ranges from 31 °C – 40 °C for the maximum and 14 °C – 24 °C for the minimum. The annual rainfall is 1,400 mm on average and varied from 1,082 mm to 1,773 mm during the last 19 years (1979 - 1998).

2.3 Economic Conditions

The major economic activities in Siem Reap Province are reported as farming 85%, fishing 5%, trading 7% and service 3%. The per capita annual income of a farmer in rural area, a fisherman in Tonle Sap area, and a trader in urban area are estimated by the Provincial Department of Planning as US\$ 80, 120 and 150, respectively. The most important agricultural practice is rice cultivation. Another major crop is sesame.

2.4 Siem Reap Town

The town is located 15 km north from the shore of the Lake Tonle Sap. The Town lies on a flatland at the elevation between 15 and 20 m. Many tourists are visiting the town to see the Angkor heritages, so tourism promotion is important for the town. A number of new hotels are under construction. A significant number of the population is engaged in the tourism sector. The residential area is condensed in an area of 2 km south to north along the River and 1 km east to west along the National Road No.6, located in the central part of the town.

The water supply facilities for the town started with the old French system in the 1930s, succeeded by an American system in the 1960s and a new groundwater system by the French urgent grant aid in 1999. The distribution system of the old American System had operated until March 1995 when the Water Supply Station stopped its public water supply service because of deterioration of water supply facilities and raw water quality of the river. The new groundwater system was completed with the two deep tube wells in October 1998. But the new system faced financial constrains due to the high electric charge. There is no provision of any generator to save running and operation costs. It was finally put into operation in late July 1999.

A managing system is presently being formulated to operate the system. Three types of operating system are considered, namely, private sector, MIME, a third sector joining with provincial governor and APSARA authority. For the time being, MIME is operating the system through Siem Reap Water Works.

At present, most of the people are using groundwater by employing shallow dug or hand pump well. A large number of these wells are contaminated by poor sanitation and high iron content.

The town area has insufficient facility for disposal of wastewater. In addition, lack of maintenance of wastewater carrying pipes and canals has compounded the problem extensively. Considering poor water management in the area, some countermeasures for wastewater treatment and improvement of the water environment of the river and the lake are also important.

2.5 Angkor Heritage

The world famous Angkor Wat heritage consists of the Theravada Buddhism temples constructed from 7th to 15th century during the Khmer Imperial Age. It is said that a few hundreds heritages exist in and around the area of Angkor Thom and Angkor Wat and their surrounding area. The structures of the heritage made by stone ware are now heavily damaged and deteriorated by weathering. The Government of Cambodia wants tourism development and to materialize that, intends to have infrastructure improvement such as water supply, road and

electricity. It is expected that the number of tourists visiting the heritage will rapidly increase. The infrastructure development for the Siem Reap Town is therefore an urgent requirement in order to accept increased tourists.

In the Khmer Imperial Age, it is believed that the Angkor area had a good water environmental condition. These include the North, East, West and Bakong Barays, the moats of Angkor Wat and Angkor Thom, and the ponds of Surah Srang, Preah Khan, Neac Pean and so on. However, most of Barays and ponds are not functioning at present except West Baray and the moats of Angkor Wat and Angkor Thom.

2.6 Potential Water Sources

In the vicinity of the Siem Reap Town, there are four potential water sources. These are the Lake Tonle Sap, West Baray, Siem Reap River, and groundwater.

(1) Lake Tonle Sap

This is the largest lake in Southeast Asia. During the wet season, water flow of the Tonle Sap River is reversed into the lake due to the flood of the Mekong River. It acts as a natural retarding basin. The water surface area varies greatly from 3,000 km² in the dry season to 10,000 km² in the rainy season. Water levels of the lake fluctuate annually from about EL.11 m in the rainy season and EL.1-2 m in the dry season.

Fishery is a major industry for the people living in boat on the lake. It is reported that more than 200 species of fish live in the lake. However, the fishery production is decreasing from 10,000 tons in the 1970s to 6,000 tons at present. The reason is inferred as a change of environmental condition, water pollution, decrease of marsh and water forest, and excessive fishing by explosives and electrical shocks. Turbidity of the lake is rather high.

(2) West Baray

The Baray was constructed in 11th century for irrigation of paddy fields extending southwest of the Baray. In ancient Khmer Imperial Age, the East Baray (Yasodharatataka), the North Baray and Bakong Baray (Indratataka) had been also constructed and used for irrigation, though the later three barays are not functioning at present.

The West Baray is located west of the Angkor heritage. It is 8 km long in east-west direction and 2.2 km wide in north-south direction. It was put back into service in 1937 and then enlarged in 1955. The water is diverted by French Weir from the Siem Reap River near Prasat Keo heritage, and conducted in rainy season through Takev Channel of approximately 5 km long (Canal A). A good water

management program of the baray for irrigation should be established for maximizing the efficiency. Also, the excavation of the land area in the eastern half might be necessary to obtain an additional storage volume for future requirement.

(3) Siem Reap River

The catchment of the river is about 600 km² with a total length of 90 km. Approximate river width is 20 m in the upstream stretch near the Angkor heritage. It is said that the river course was artificially changed with the construction of the West Baray, North Baray and the East Baray. There are two weirs in the river. One is 'French Weir' constructed at about 10 km upstream from the town center to divert the river water to the West Baray. The other is called 'Crocodile Weir' constructed for irrigation intake, located downstream of the town.

It seems that the river improvement is important to keep a maintenance flow especially in dry season from environmental aspect.

(4) Groundwater

Groundwater is used for domestic purposes in the Study area by shallow hand pump wells or dug wells. Most of the hotels have their own deep tube wells with purification system. The shallow groundwater in the vicinity of the town contains high iron caused by subsurface laterite layer, and polluted by wastewater due to poor drainage.

The CFD (Caisse Francaise de Developpement) drilled 2 deep tube wells (40 m deep) in 1997 for the urgent aid of the new water supply system. The new system by CFD started operation in July 1999.