NO.

BASIC DESIGN STUDY REPORT
ON
THE PROJECT FOR EXPANSION
OF
PHUM PREK WATER TREATMENT PLANT
IN
THE KINGDOM OF CAMBODIA

JANUARY 2001

JAPAN INTERNATIONAL COOPERATION AGENCY

TOKYO ENGINEERING CONSULTANTS CO., LTD

NIHON SUIDO CONSULTANTS CO., LTD

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PREFACE

In response to a request from the Royal Government of Cambodia the Government of Japan decided to conduct a basic design study on the Project for Expansion of Phum Prek Water Treatment Plant and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA send to Cambodia a study team from June 10 to August 1, 2000.

The team held discussions with the officials concerned of the Royal Government of Cambodia, and conducted a field study at the study area. After the team returned to Japan, further studies were made. Then, a mission was sent to Cambodia in order to discuss a draft basic design, and as this result, the present report was finalized.

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

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

January 2001

Kunihiko Saito
President
Japan International Cooperation Agency

January, 2001

Letter of Transmittal

We are pleased to submit to you the basic design study report on the Project for Expansion of Phum Prek Water Treatment Plant in the Kingdom of Cambodia.

This study was conducted by Tokyo Engineering Consultants Co., Ltd. and Nihon Suido Consultants Co., Ltd., under a contract to JICA, during the period from June 10, 2000 to January 26, 2001. In conducting the study, we have examined the feasibility and rationale of the project with due consideration to the present situation of Cambodia and formulated the most appropriate basic design for the project under Japan's grant aid scheme.

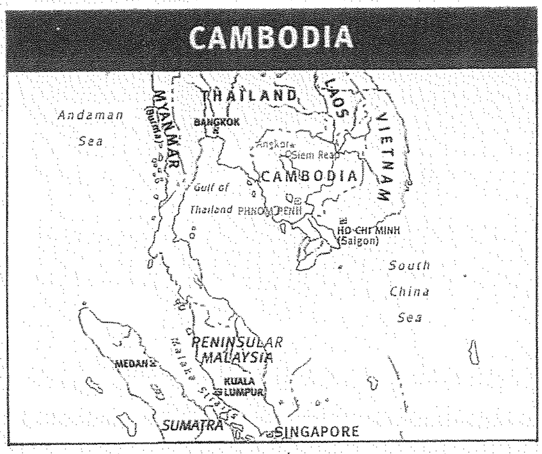
Finally, we hope that this report will contribute to further promotion of the project.

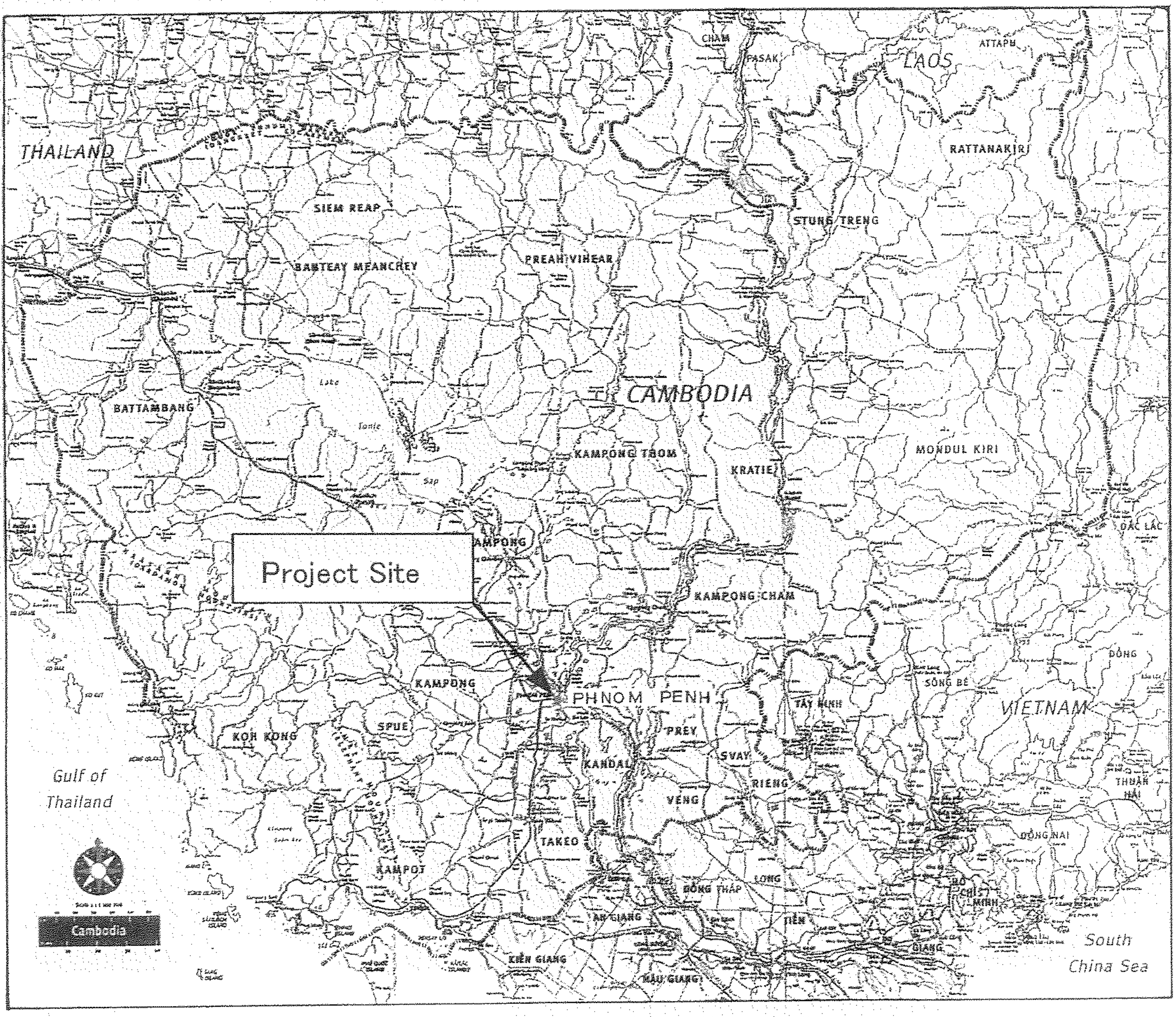
Very truly yours,

芳賀秀寿

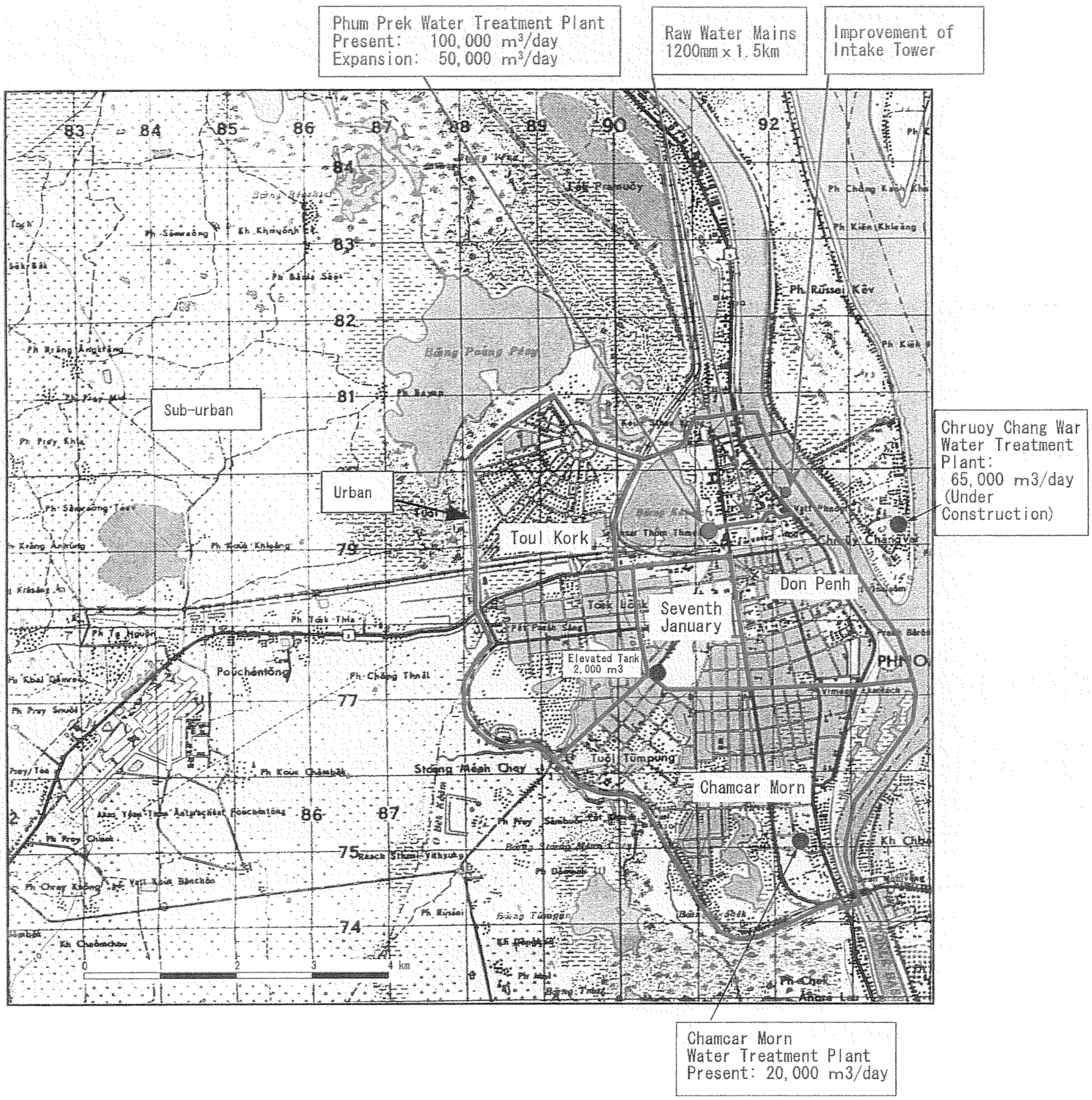
Hidetoshi Haga
Project Manager
Basic design study team on
the Project for Expansion of
Phum Prek Water Treatment Plant

Tokyo Engineering Consultants Co., Ltd.
Nihon Suido Consultants Co., Ltd.



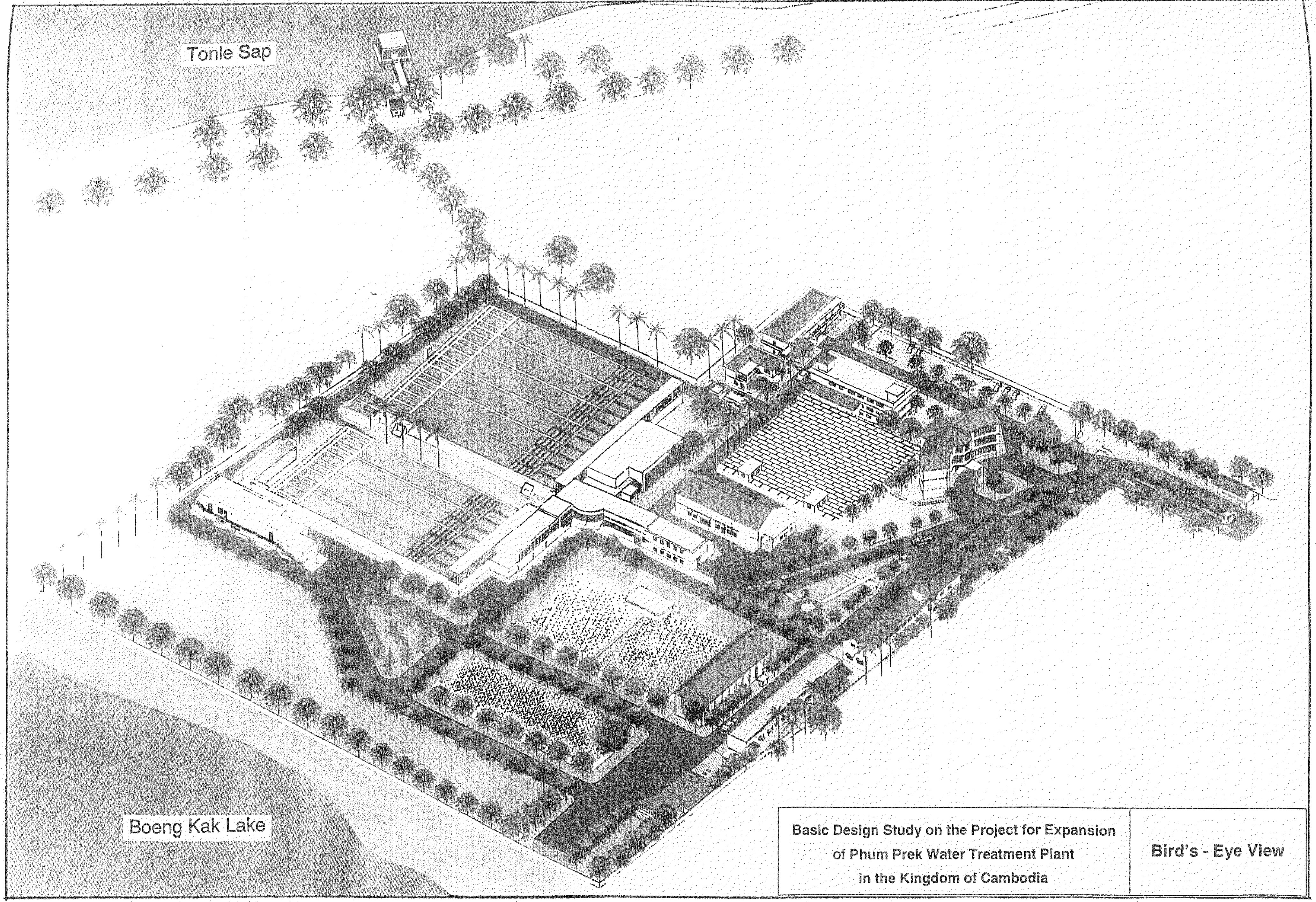


Location Map



PROJECT SITE OF PHNOM PENH CITY

- Major Water Supply Facilities and Planned Phum Prek Water Treatment Plant -



Basic Design Study on the Project for Expansion of Phum Prek Water Treatment Plant in the Kingdom of Cambodia

Bird's - Eye View

Abbreviations

B/D	Basic Design
DTP	Department of Technical and Project
GOC	Royal Government of Cambodia
GOJ	Government of Japan
JICA:	Japan International Cooperation Agency
MPTC	Ministry of Post and Telecommunication
MWRM	Ministry of Water Resource and Meteorology
O & M	Operation and Maintenance
PPWSA	Phnom Penh Water Supply Authority
W/P	With Project
WO/P	Without Project
WTP	Water Treatment Plant

Preface
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Location Map/Project Site/Bird's-Eye View
Abbreviations

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CHAPTER 1

BACKGROUND OF THE PROJECT

Chapter 1 Background of the Project

Water supply situation in Phnom Penh was deteriorated to an extreme degree as a result of damage and poor maintenance of the water supply facilities during the civil war period of Cambodia. In the 1991 Paris Accord, international donors and agencies including the Government of Japanese (GOJ) offered support for the restoration of the water supply system in Phnom Penh.

In 1993, GOJ implemented a development study with the objective of restoring the water supply system of the city and a water supply Master Plan having year 2010 as the target year was formulated. In the Master Plan, urgent rehabilitation works (URW), which were required to be implemented immediately, were identified and compiled.

In 1994, GOJ implemented the project for Improvement of Water Supply Facilities in Phnom Penh (Phase I) in which some of the URW were targeted. As a result, the water production capacity of Phum Prek water treatment plant (WTP) was restored to 100,000 m^3/day from 56,000 m^3/day.

After completion of Phase I, GOJ started Phase II project, which consisted of renewal of the distribution pipe network with the area of 67 km^2 in the 7th January district and a part of the Toul Kork district. This project was completed in February 1999. Other donors and international agencies also have assisted for renewal of the distribution network in other districts of the Phnom Penh city and the distribution network has been restored.

Besides, various water supply projects have been implemented by Phnom Penh Water Supply Authority (PPWSA) with international assistance and consequently the water supply situation in the city has been improved. However, the water production capacity is still far short of water demand of the city. In January 1997, for the purpose of increase in the water production capacity, the Royal Government of Cambodia (GOC) made a request to GOJ for a grant-aid Project for the Expansion of Phum Prek Water Treatment Plant (the Project).

The requested Project consists of expansion of Phum Prek WTP by 50,000 m^3/day, improvement of intake facilities, installation of additional raw water main, and construction of distribution reservoir of 10,000 m^3 and installation of a distribution pump. The components of the request are as shown in Table 1-1-1.

In response to the request, Japan International Cooperation Agency (JICA) dispatched a Study

Team to Cambodia in June 2000 to conduct a basic design study (the Study) on this Project. During the discussion on the Inception Report, GOC made a modified request to the JICA Study Team as shown in Table 1-1-1.

Table 1 2 - 1-1 Contents of the Request of the Cambodian Side

Facilities/ Equipment	Contents of Original Request	Contents of Modified Request
Intake facilities	・ Rehabilitation of intake facilities	・ Renewal of 3 intake pumps (2200 m^3/hour each) ・ Installation of 2 new intake pumps (2200 m^3/hour each) for expanded WTP
Raw water facilities	・ Installation of new raw water main (φ700 mm x 1.5 km)	・ Installation of new raw water main (φ1200 mm x 1.5 km)
Water treatment facilities	・ Construction of new raw water receiving well, rapid mixing basin, flocculation basin, chemical sedimentation basin and rapid filter (50,000 m^3/day)	・ Construction of new raw water receiving well, rapid mixing basin, flocculation basin, chemical sedimentation basin and rapid filter (50,000 m^3/day)
Chemical facilities	・ Construction of new chemical feeding facilities (50,000 m^3/day)	・ Construction of new chemical feeding facilities (150,000 m^3/day) ・ Expansion of water quality analysis laboratory and instrumentation
Distribution reservoir	・ Construction of new 10,000-m^3 reservoir	・ Construction of new 10,000-m^3 reservoir (total water storage time : 5.1 hours)
Distribution pump	・ Installation of 1 new distribution pump	・ Renewal of 3 distribution pumps (2100m^3/hour each) ・ Installation of 1 new distribution pump (1050 m^3/hour each)

Notes: The priority indicated by PPWSA for the modified requests is as given below.
1. First Priority: Expansion of facilities/equipment (2 new intake pumps, raw water main, water treatment facilities, chemical feeding facilities, 1 distribution pump) and renewal of 3 distribution pumps as part of the rehabilitation work
2. Second priority: Renewal of 3 existing intake pumps

CHAPTER 2

CONTENTS OF THE PROJECT

Chapter 2 Contents of the Project

2 - 1 Objectives of the Project

The objectives of the Project are to increase the served population by the city's water supply through the expansion of Phum Prek WTP, and to provide sanitary safe water with appropriate pressure to the city through the rehabilitation and improvement of the existing facilities.

The scope of the Project by GOJ is the expansion of the Phum Prek WTP. The expansion facilities include intake facilities, raw water main, treatment facilities, distribution reservoir and distribution pump. In addition, the minimum required rehabilitation of the existing facilities are added to the scope to improve treated water quality of the existing water treatment plant, which is not included in the original request.

The optimum facilities as determined from the Study are summarized in Table 2-1-1. This table also compares the contents of the original and modified requests made by GOC.

Table 2-1-2 summarizes the results of the Study, describing major existing facilities, contents of the Study, proposed usage policy for the existing facilities/equipment and the optimum (proposed) facilities/equipment.

Table 2 - 1-1 Description of Required Facilities based on the Requests Received and the Results of B/D Study

Requested Facilities/ Equipment	Contents of Original Request	Contents of Modefied Request	Contents of Optimum Facilities (proposed by Study Team based on results ofthe study)		Objectives of the Works
			New Facilities	**Modification of Existing Facilities**	
Intake facilities	• Rehabilitation of intake facilities	• Renewal of 3 intake pumps (2200 m^3/hour.) • Installation of 2 new intake pumps (2200 m^3/hour.) for expanded WTP Total 5 pumps	• Installation of 2 new intake pumps (2200 m^3/hour.; 1 standby) for expanded WTP Total 2 pumps	• Renewal of 1 existing intake pump (2200 m^3/hour.) Total 1 pumps	• To secure appropriate raw water intake capacity for the expansion of Phum Prek WTP
Raw water facilities	• Installation of new raw water main (φ700 mm x 1.5 km)	• Installation of new raw water main (φ1200 mm x 1.5 km)	• Installation of new raw water main (φ1200 mm x 1.5 km)	• Existing raw water main to be used as standby.	• To secure necessary raw water conveyance capacity
Water treatment facilities	• Construction of new raw water receiving well, rapid mixing basin, floccuration basin, chemical sedimentation basin and rapid filter (50,000 m^3/day.min.)	• Construction of new raw water receiving well, rapid mixing basin, floccuration basin, chemical sedimentation basin and rapid filter (50,000 m^3/day)	• Construction of new raw water receiving well and rapid mixing basin (150,000 m^3/day) • Construction of new flocculation basin, chemical sedimentation basin and rapid filter (50,000 m^3/day.)	• Existing raw water receiving well and rapid mixing basin to be used as standby. • Installation of baffle wall in chemical sedimentation basin.	• To increase treated water volume • To improve treated water quality by rehabilitating the existing facilities (improvement of treatment efficiency in the existing sedimentation basin)
Chemical facilities	• Construction of new chemical feeding facilities (50,000 m^3/day)	• Construction of new chemical feeding facilities (150,000 m^3/day) • Expansion of water quality analysis laboratory and instrumentation	• Construction of a new chemical building including water quality analysis labratory • Installation of new gravity chemical feeding equipment (150,000 m^3/day) • Supply of equipment and instruments for water quality analysis	• The existing facilities/equipment will not be use. The capacity of the existing ones is included in new facilities.	• To improve treated water quality by feeding appropriate amount of chemicals • To improve capacity of water quality analysis and monitoring of water quality
Distribution reservoir	• Construction of new 10,000-m^3 reservoir	• Construction of new 10,000-m^3 reservoir (total water storage time : 5.1 hours)	• Construction of new 5,000-m^3 reservoir (total water storage time : 4.3 hours)	—	• To secure appropriate water supply amount with appropriate pressure by reserving appropriate volume of treated water
Distribution pump	• Installation of 1 new distribution pump	• Renewal of 3 distribution pumps (2100m^3/hour.) • Installation of 1 new distribution pump (1050 m^3/hour.)	• Installation of 1 new distribution pump (1050 m^3/hour.)	• Renewal of 3 distribution pumps (2100m3/hour.)	• To secure appropriate water supply pressure at demand points in water service area • To increase water distribution capacity
Connection pipes in the plant	—	—	• Connection pipes in the plant	—	• Necessary facilities connecting new and existing facilities

Notes: The priority indicated by PPWSA related to the modified requests is as given below.

3. First Priority: Expansion of facilities/equipment (2 new intake pumps, raw water main, water treatment facilities, chemical feeding facilities, 1 distribution pump) and renewal of 3 distribution pumps as part of the rehabilitation work
4. Second priority: Renewal of 3 existing intake pumps

Table 2 - 1-2 Summary of Studies Related to Facilities Requested (1/2)

Facilities/ equipment/others	Existing Facilities	Study Items	Usage policy of existing water treatment facilities/equipment	Results of study
Scale of WTP	Treated water capacity of 100,000 m^3/day	• Study of scale of WTP • Study of the water treatment capacity	—	Expand by 50,000 m^3/day (total 150,000 m^3/day) Total water treatment capacity 158,400 m^3/day including water used within the WTP
Intake facilities/ equipment	Intake tower	—	Use of existing facilities	—
	3 pumps (2,200 m^3/hour)	• Functions of existing pumps • Required pump capacity	Use 2 existing pumps	Install 2 new pumps and Renew 1 existing pump, total 3 pumps
Raw water facilities	Raw water mains 700 mm x 2	• Functions of existing raw water mains • Installation of new pipelines	Use existing raw water mains during an emergency and during cleaning of new raw water main	Install new raw water mains (150,000 m^3/day) 1200 mm x 1.55 km approx.
	Anti-water hammering equipment	• Study of water hammering action	Dispose of the equipment because of corrosion	Install new anti-water hammering equipment

Table 2 - 1-3 Summary of Studies Related to Facilities Requested (2/2)

Facilities/ equipment/others	Existing Facilities	Study Items	Usage policy of existing water treatment facilities/equipment	Results of study
Water treatment facilities	1 raw water receiving well and 2 rapid mixing basins	• Configuration of facilities	Use existing facilities as standby or emergency	Install 1 new basin (150,000 m^3/day)
	Flocculation facilities - 6 basins	• Functions of existing facilities	Use existing facilities	Install new facilities (50,000 m^3/day)
	Chemical sedimentation basins - 6	• Treatment method		Install new facilities (50,000 m^3/day)
			Improve existing facilities due to poor function	Install baffle wall in the inlet part
	Rapid filtering facilities - 12 basins		Use existing facilities	New installation (50,000 m^3/day)
	Back washing facilities		Use existing facilities	Existing facilities can be used as part of expanded facilities
	Drainage facilities (discharge of sludge)		Use existing facilities	Existing facilities can be used as part of expanded facilities
Chemical building/feeding equipment	Chemical building and feeding equipments (100,000 m^3/day)	• Functions of existing equipment	Dispose of existing facilities due to aging	Construct new chemical building including water quality analysis laboratory Install chemical feeding equipment (150,000 m^3/day) Supply water quality analysis equipment and instruments
Distribution facilities	Distribution reservoir 20,000 m^3	• Required additional capacity of distribution reservoir	Use existing facilities	Construct 1 new reservoir (5,000 m^3)
	4 distribution pumps (2100 m^3/hour)	• Functions of existing pumps	Renew 3 existing pumps, use 1 pump	Renew 3 distribution pumps(2100 m^3/hour)
	2 transmission pumps (1050 m^3/hour)	• Required capacity of additional pumps	Use existing pumps	Install 1 new distribution pump (1050 m^3/hour)
	2 distribution pumps (1050 m^3/hour)		Use existing pumps	

2 - 2 Basic Design

2 - 2 - 1 Design Concept

To consider facilities and equipment that suit the conditions (construction, maintenance and operations technologies, finance, society) of Cambodia and the PPWSA, major items relevant to the design are summarized as given below and adopted as design guidelines.

(1) Scope of basic design

The scope of the basic design is the expansion and rehabilitation/improvement of the Phum Prek WTP. The expansion of the WTP includes construction of intake facilities, raw water main, treatment facilities, distribution reservoir, and distribution pump facilities. The rehabilitation of the existing facilities essential for improving treated water quality and for the effectiveness of expanded facilities is considered.

(2) Adoption of facilities of simple construction

Similar to the problem generally faced by other developing countries, the acquisition of spare parts for machinery and electrical equipment is a major problem encountered by the PPWSA. Although the income statement of the PPWSA shows that it does make some profits, the profits are not adequate to procure expensive spare parts in time. This is the main reason for the difficulty in procuring spare parts. As facilities and equipment become more complex, the number of spare parts required increase. Practically no parts can be procured locally. Procurement by importing these parts from other countries incurs considerable time and leads to excessive delays. As a result, equipment that suffers breakdowns can remain non-operational for a long period of time. If the equipment that failed is an important equipment for water treatment, then the situation can become much more serious, and a stable supply of safe drinking water cannot be ensured. Generally, if equipment of simple construction fails, it can be repaired adequately using local skills and technology. On the other hand, if the equipment is complex, its repair by local resources is difficult and at times impossible. In view of the above considerations, emphasis should be laid on selecting facilities and equipment with simple construction that satisfy the desired performance.

(3) Improving the ease of operation of facilities

The simplicity in structure of equipment and its ease of operation are two different matters. Even if the structure is simple, the equipment may not be easy to operate. When individual equipment are assembled together to form the water treatment system, the ease of operation of the entire system (including monitoring of equipment operations) becomes very important. The ease of operation of the system affects not only the management of operations of the WTP but also the operating efficiency of the plant.

The quality of the raw water changes from time to time, which requires adequate operation and measures to ensure good quality of treated water through the WTP. If the ease of operation of the system is poor, the operator finds it difficult to adopt measures to suit the changing conditions. The result is that excessive chemicals are added to the water, or the required chemical quantity is not added to the water.

The water level of the Tonle Sap fluctuates by as much as 10 meters in a year. Accordingly, the water quantity pumped up to the WTP fluctuates, which makes the pump operation very difficult. If the ease of operation is poor, more or less raw water is delivered than that is required for the WTP. As a result, the excess treated water is returned to the river or less treated water is produced.

If the ease of operation is poor, it may sometimes lead to accidents also. To minimize such problems and accidents, the basic design of the facilities should be implemented giving importance to the ease of operation.

(4) Utilization of local resources

Reduced project costs and better economic impacts on the country can be anticipated by increased utilization of local resources. Increased utilization of local resources in the servicing and repairs of facilities is particularly beneficial for the country. In view of the above considerations, the basic design should incorporate increased utilization of local resources.

(5) Effective utilization of existing facilities and avoidance of duplication

Many of the facilities and the equipment in the Phum Prek WTP have aged excessively and need to be repaired or replaced. Besides, some of the facilities are not functioning effectively, therefore stable quality of water cannot be ensured. Considering the above and considering the simplification of maintenance and operations of the plant, a part of the existing structures should preferably be modified.

Considering that the total daily distribution volume of 150,000 m^3 and satisfactory quality of the treated water are to be ensured after implementation of this project, emphasis needs to be placed on effective utilization of the existing facilities and equipment, based on the pre-requisite that the minimum required rehabilitation are carried out.

Duplication of the facility or equipment should be avoided. If the existing facility or equipment, e.g., filter back-washing equipment and sludge discharge facility can ensure appropriate capacity for the expanded facility including the existing one, such facility or equipment should be used for the expanded facility.

(6) Energy savings in the water treatment processes

Presently, a part of the raw water overflows in the WTP and is being discharged back to the river without being used. This is evidently a case of unnecessary wastage of energy. There are some locations in the plant where energy is being wasted. Such losses should be prevented so that maintenance and operating expenses of the WTP can be reduced. Accordingly, the basic design should focus on energy savings.

(7) Systematization of water treatment processes

Processes in the water treatment facilities should be systematized as far as possible so that each system can be operated independently. This would enable proper maintenance and inspection of each facility in the system, and also lead to satisfactory maintenance and operation of the entire plant.

(8) Guidelines related to the construction site

The land for the new facilities is ready. The area of the land is adequate for carrying out the expansion work. The following permissions related to the land for new facilities have already been obtained.

- Installation of a new raw water main in the public land of the Phnom Penh city and the land belonging to the Ministry of Post and Telecommunication (MPTC).

- Registration of the landfill for the site of a proposed new reservoir.

Based on the results of soil tests, it is confirmed that the soil strength at the construction site is satisfactory and there is no problem for constructing concrete structures on it. The optimum foundation support method should be used, based on the findings of soil tests.

(9) Guidelines related to quality standards for treated water

Presently, WHO standards are used by the PPWSA for the distributed water quality. The quality of water distributed to the city from the existing and expanded Phum Prek WTP should satisfy WHO water quality standards. Currently, the removal of turbidity components in water at the existing WTP is inadequate. Minimum improvements necessary for removal of these components should be made in the existing facilities.

(10) Design standards

Cambodian and Japanese standards are properly used for the design.

(11) Conformance of expanded facilities with the existing facilities

The expanded facilities should be constructed and arranged such that upon completion of the project, the existing and expanded facilities should comprise of a single water treatment plant with a total water treatment capacity of 150,000 m^3/day, capable of being rationally operated and maintained.

Design of structure and appearance of the expanded facilities should be basically similar to the existing ones to match the atmosphere around and within the WTP.

The expanded facilities should make use of the same treatment methods as used in the existing facilities to enable easy maintenance and operation.

12) Guidelines of natural conditions

No damage by earthquake has been identified; earthquake-resistant design is not considered.

Design for anti-freezing during installation of pipes need not be considered because of the tropical climate.

Groundwater level is around 1 m below the ground and it should be considered during design.

2 - 2 - 2 Design Criteria

(1) Target Year

The Project facilities will be completed and commissioned in year 2004. The target year of the project shall be the following year, i.e. year 2005. The water demand, however, is projected until 2015 to identify the required water supply facilities after this project for reference.

(2) Water Supply Service Level

The target water supply service level in Phnom Penh in the target year is indicated in Table 2-2-1 together with the current level. Based on this, items related to the water demand projection are explained.

Table 2 - 2-1 Target Water Supply Service Level in the Area Covered by Phum Prek WTP

Service Item	Service Level/Population		Remarks
	Present (2000)	2005	
Phnom Penh city			
Total population	1,040,000	1,342,000	See population forecast
Urban population	553,000	653,000	See population forecast
Suburban population	487,000	689,000	See population forecast
Phum Prek WTP service area			
Capacity of Phum Prek WTP	100,000	150,000	WTP is expanded in this project.
Population in the area	492,000	545,000	About 84 % of urban population in 2005 falls in Phum Prek WTP served area. (the Study Team estimate)
Population served by PPWSA	332,000 *	545,000	See population forecast
Ratio of population served by PPWSA	60 % *	100 %	Computed from the total population and served population
Per capita daily water supply for domestic use	132 l/day/person *	132 l/day/person	the planned value for the urban area
Domestic water demand	44,000 m^3/day	86,000 m^3/day	60 % of total effective water
Water demand other than domestic use	19,100 m^3/day	48,000 m^3/day	40 % of total effective water
Revenue (effective) water ratio	65 % *	80 %	PPWSA plan
Leakage ratio (%)	about 30 % *	80 %	Same as the revenue water ratio
Daily maximum demand (m^3/day)	about 100,000	150,000	See the demand forecast. (presently water demand is depressed)
Supply pressure	0-10 m most area *	25-30 m	Water can be supplied to the fifth floor in urban water supply districts.
Supply water quality	WHO standard is not satisfied.	WHO standard is satisfied.	Supply of drinkable water

Note: * The values are computed from service levels in the whole area presently covered by PPWSA water supply.

(3) Population Forecast

The past population, population density and population growth rate by district of Phnom Penh are tabulated in Table 2-2-2. The yearly average population growth rate of the Phnom Penh city was 5.41 percent during the period from 1992 to 1998, which are very high compared with the Cambodian average of 2.3 percent. The main reason of this high growth in population can be due to the high influx of immigrants into Phnom Pen, the Capital City of Cambodia, after the civil war. This trend of influx of immigrants will be continued in future.

Table 2 - 2-2 Past Population and Density and Growth Rate

District	Area (km^2)	1992 population by Phnom Penh municipality	1994 Population estimated by PPWSA	1998 population by Phnom Penh municipality	1998 Census population	1998 population density (Persons/ha)	Average annual population growth rate between 1992 and 1998
	(1)	(2)	(3)	(4)	(5)	(4)/(1)	(2) and (4)
Urban							
Don Penh	7.60	106,907	118,344	118,501	131,913	156	1.73
7th January	2.35	87,840	97,238	92,771	96,192	395	0.91
Chamcar Morn	9.50	111,301	123,209	162,565	187,082	171	6.52
Tuol Kork	9.25	96,022	106,295	141,838	154,968	153	6.72
Sub-total or average	28.70	402,070	445,086	515,675	570,155	180	4.23
Sub-urban							
Rusey Keo	99.06	120,108	132,958	168,515	180,076	17	5.81
Dang Kor	112.67	63,381	70,162	92,978	92,461	8	6.60
Mean Chey	44.00	97,377	107,795	159,599	157,112	36	8.58
Sub-total or average	255.73	280,866	310,914	421,092	429,649	16	6.98
Total or average	284.43	682,936	756,000	936,767	999,804	33	5.41

Source: Tabulated from General Population Census of Cambodia 1998, PPWSA, and World Fact Book

Fifty-five percent of the total population is less than 24-years old. The city has very young population so that it has high potential of high birth rate in future. The high immigration rate and birth rate will keep the population increase high in future.

In the urban area, the streets are well developed and the population density is high (180 persons/ha), especially in the 7th January district, which is about 400 persons/ha. The average population growth rate of the 7th January district between 1992 and 1998 is as low as less than 1 % and the houses are clustered close together. It can be estimated that the population is almost saturated. In order to sustain increase in the population in the area, high-rise housing building will be required. In the Chamcar Morn and Toul Kork district, houses are clustered close together but the population is still increasing with the high growth rate of more than 6.5 per annum.

In the suburban area, generally, residential type can be categorized into two types: rural village type very often seen in the Dang Kor district and community type close to urban residential style seen in the Mean Chey district. In the suburban area, communities are developed only along the street and the rest of the vast land is used for agriculture and wetlands. Therefore, the population density (16 person/ha) is very low and this area has high potential of high population increase if urban development shifts from the existing urban to the suburban.

Since no city plan has been formulated for the Phnom Penh city it is very difficult to forecast the future population. For this basic design study, the population is forecasted by 3 population scenarios as below and as shown in Table 2-2-3.

- **Scenario A** (high growth scenario): Population increase rate in the urban area goes down, while the rate of increase in suburban area is crossed over (forecasted by PPWSA).
- **Scenario B** (medium growth scenario): the intermediate value of population between scenario A and C.
- **Scenario C** (Low growth scenario): Population in both the urban and suburban areas goes down.

Table 2 - 2-3 Population Growth Rate Scenarios

	Actual Growth Rate 1992-1998	Scenario A (PPWSA)	Scenario B (Medium Growth)	Scenario C (Low Growth)
Contents	—	Forecast made by the PPWSA. Population increase rate in the urban area goes down, while the rate of increase in suburban area increases.	The population is an intermediate value between Scenario A and Scenario C.	Population in the urban area and suburban area gradually go down from the 1998 figures of 4.23% to 1.5% for the urban and from 6.98% to 3.5% for the suburban in 2015.
Annual average rate of population growth between 1999 and 2015				
Urban area	4.23%	3.47%	3.13%	2.98%
Suburban area	6.98%	8.46%	7.00%	5.13%
Average	5.41%	6.18%	5.15%	3.94%

Note: See Appendix, for details.

The results of population forecast for the three scenarios are shown in Table 2-2-4. Scenario A shows the case of high population increase, while Scenario C shows the case of low population increase. There is a strong possibility that the future population will fall somewhere between these two scenarios, and it is thought that Scenario B showing the intermediate value between both scenarios is the likely population forecast. The population forecast of Scenario B shall be used in this Project. According to this, total population of the city in year 2005 is expected to be 1,342,000.

Table 2 - 2-4 Population Forecast

(unit: 1,000 people)

	1998	2000	2005	2010	2015
Scenario A (PPWSA)					
Total population	937	1,043	1,386	1,878	2,595
Urban area	516	549	647	768	920
Suburban parts	421	494	739	1,110	1,675
Scenario B					
Total population	937	1,040	1,342	1,722	2,201
Urban area	516	553	653	760	871
Suburban parts	421	487	689	962	1,330
Scenario C					
Total population	937	1,037	1,300	1,565	1,808
Urban area	516	558	660	751	822
Suburban parts	421	479	640	814	986

(4) Water Demand Forecast

1) Water consumption

Water consumption of the Phnom Penh city by district and consumer type in 1998 and 1999 is summarized in Table 2-2-5. Of the total consumption, about 60 % is consumed by domestic user and almost 99 % is consumed in the urban district.

Table 2 - 2-5 PPWSA Water Consumption by District and Consumer Type

(unit:m^3/day)

	1998 年					1999 年				
	Domes.	C&I	Adm.	WS	total	Domes.	C&I	Adm.	WS	total
Don Penh	9,290	4,821	3,349	365	17,825	9,854	5,330	3,755	332	19,271
7th January	5,850	2,651	582	279	9,362	7,060	2,940	697	143	10,840
Chamcar Morn	7,664	3,525	820	400	12,409	10,805	4,474	1,238	241	16,758
Toul Kork	5,096	1,675	564	240	7,575	6,213	2,158	826	268	9,465
Russey Keo	300	104	92	186	682	367	152	79	153	751
Mean Chey	52	43	0	3	98	41	52	0	2	95
Dan g Kor	0	0	0	0	0	0	0	0	0	0
合計	28,252	12,819	5,407	1,473	47,951	34,340	15,106	6,595	1,139	57,180
%	58.9	26.7	11.3	3.1	100.0	60.1	26.4	11.5	2.0	100.0

Source: PPWSA

Note: Domes. (Domestic), C&I (Commercial and Industrial), Adm.(Administration), WS (Wholesaler)

2) Procedure of demand forecast

The water demand by urban and suburban and by consumer type is forecasted according to the procedure in Figure 2-1-1.

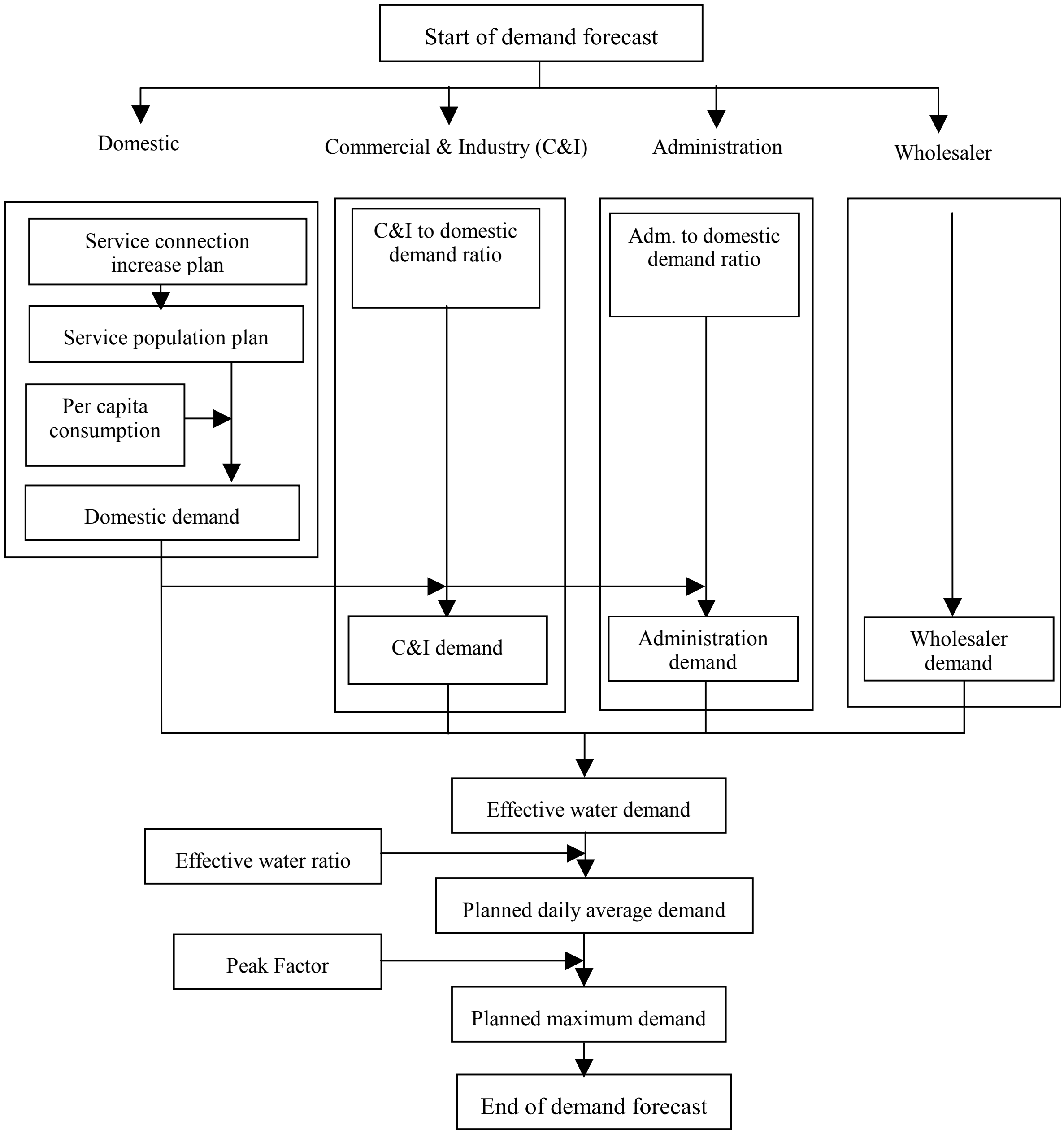


Fig. 2 - 2-1 Procedure of Water Demand Forecast

3) Water service connection increase

The PPWSA has increased service connections by 7,000 to 10,000 per year in the past three years as shown in Table 2-2-6. The annual number of connection increase in year 2000 will be 10,000 based on the result of the increase in the first half period of 2000.

Table 2 - 2-6 Result of Annual Increase of Service Connection

Year	1997	1998	1999
Annual increase	8,917	7,298	9,631

Source: PPWSA

The maximum capacity of service connection increase by PPWSA is 90 connections per day, which means 23,500 connections per year assuming 5 working days per week. The PPWSA has a setup whereby it is possible to surely implement the increase of service connections by 15,000 per year. For this plan, the number of connections increased is planned as 12,000 connections in 2001 and as 18,000 connections per year after 2002 assuming 4 working days per week. The planned increase of the service connection are summarized in Table 2-2-7.

Table 2 - 2-7 Planned Annual Increase of Service Connection

Year	2000	2001	after 2002
Planned annual increase	10,000	12,000	18,000

Percentage of domestic connections of the total connections is 85.5% at the beginning of 2000 as shown in Table 2-2-8. This percentage is applied to the future increase of domestic connection assuming the present trend of connection ratio will not change. As a result, the planned annual increase of domestic connection is 15,390, which is equivalent to annual increase of the served population of 87,723 assuming 5.7 persons per household.

Table 2 - 2-8 Service Connection at February in 2000

District	Domestic	C & I	Administration	Wholesaler	Total
Don Penh	12,450	2,290	183	49	14,972
7th January	12,482	1,900	63	26	14,471
Chamcar Morn	15,822	2,548	91	39	18,500
Toul Kork	11,487	1,531	49	54	13,121
Russey Keo	398	96	4	19	517
Mean Chey	67	20	1	1	89
Dang Kor	0	0	0	0	0
Total	52,706	8,385	391	188	61,670
Percentage (%)	85.5	13.6	0.6	0.3	100.0

Source: PPWSA

4) Served population and service rate

Served population and service coverage rate calculated based on the following assumptions and rules and the result is shown in Table 2-2-9.

a) Urban area

The served rate will reach to 100 percent in 2005 for the urban area. The water supply by wholesalers is expected to be disappeared in 2005. The service coverage rates between 2000 and 2005 shall be set by interpolating the values between 2000 and 2005.

b) Suburban area

The first priority of connection increase shall be put on the urban area as stated above and the residual number of the total connections shall be used for increase of connections in the suburban area. Therefore, the number of connection increased in the suburban area is calculated by subtracting the service connection increase for the urban area from the total planned connections. The served population and service coverage rate for the suburban area can be calculated from the planned connection increase. The present served area of wholesalers shall be first covered by the PPWSA water supply and the wholesaler's water supply is expected to be disappeared in 2005.

Table 2 - 2-9 Planned Service Rate of PPWSA Water Supply

(unit: %)

District Year	2000(Actual)	2005	2010	2015
Urban	60	100	100	100
Suburban	0.5	12.5	43.2	55.6
Total Phnom Penh	32	55	68	73

5) Per capita consumption for domestic use

The per capita consumption for domestic use by district in the Phnom Penh city for 1998 and 1999 is tabulated in Table 2-2-10.

Table 2 - 2-10 Per Capita Consumption for Domestic Use by District

(unit: m^3/person/day)

District Year	1998	1999
Don Penh	141	145
7th January	109	104
Chamcar Morn	143	150
Toul Kork	133	128
Russey Keo	144	170
Mean Chey	190	132
Dan g Kor	N.D.	N.D.
Average of all districts	132	133
Average of the urban districts	132	132

Per capita consumption for domestic use depends on climate, water resource potential for water supply, living style, living standards, diffusion of water-use equipment, water tariff, etc. in the area. A typical example of water consumption by housing class in the developing countries is shown in Table 2-2-11.

Table 2 - 2-11 Typical Example for Per Capita Consumption in Developing Countries by Housing Class

Housing class	Housing style	Water consumption (L/person/day)
High	Detached houses, luxury apartments, having 2 more toilets and 3 more taps per household	260 - 150
Middle	Houses and apartment having at least 1 toilet and 2 taps per household	160 - 110
Low	Tenants, government housing, shared houses, having at least 1 tap per household but sharing toilet	70 - 55

Source: Dangerfield B.J. (1983) Water Supply Manuals, 3. Water Supply and Sanitation in developing Countries. IWES. London.

The planned per capita domestic consumption by the urban and suburban area for the Phnom Penh city is set as follows.

a) Urban area

The current value of the average per capita domestic water consumption of the urban area in 1998 and 1999 (132 L/person/day) shall be used for the planned per capita consumption for the urban area as explained below.

- Generally, higher the living standard or the income, the more per capita water consumption. The people in the urban area have higher possibility to increase their living standard and income in future. According to the increase, the water consumption will increase.
- Currently, the PPWSA water is mainly supplied to the relatively higher income people and is not supplied so much to the poor communities in the urban area. PPWSA has a policy to intensively increase service connections for the poor people or lower income people. Therefore, the service connections for the poor people will increase. Generally, the per capita consumption of the poor people is lower than that of higher income people. Therefore, the more the service connections for the poor people increases the more average per capita consumption for the urban area decreases.
- In August 2000 electricity tariff was raised and thus the water supply costs got increased. The water tariff is also considered to be raised. If the water tariff is raised the water consumption can decrease.
- Considering the above, the planned per capita consumption for the urban area until 2015 is the same as the current consumption level.

- The adopted per capita consumption (132 L/person/day) is equivalent to middle class housing according to Table 2-2-11 and is the appropriate consumption level for the per capita domestic consumption of the urban area in the Phnom Penh city.

b) Suburban area

In the suburban area, generally, low-income people live and their water consumption is supposed to be smaller than the urban area. However, as shown in Table 2-2-10, the current per capita consumption of the suburban area is larger than the urban area. This present high per capita consumption together with the very small number of the service connections and the very small amount of water consumption in the suburban area as shown in Table 2-2-5 and Table 2-2-8 may indicate that only high-income people in the suburban area can afford to connect to the PPWSA water supply.

A proper per capita consumption for the suburban area shall be adopted for the future plan. The per capita consumption of 100 L/day is adopted for the suburban area with reference given to the actual value (104 L/person/day) of the 7th January district, which has the smallest consumption in the urban districts. The adopted value is equivalent to the per capita consumption level of the low or middle class housing, which dominates in the suburban area.

6) Non-domestic water demand

Generally, water consumption for non-domestic use (commercial, industrial and administrational use) increases in proportion to increase of population and human activities. For this plan, therefore, future non-domestic water consumption is estimated by proportioning future domestic consumption, i.e., the future non-domestic water consumption is calculated from multiplying the current ratio of non-domestic to domestic water consumption by planned domestic water consumption. The ratio of non-domestic to domestic water consumption is planned as follows.

a) Urban area

The actual ratio from 1999 is adopted for the plan of the urban area.

- Ratio of commercial and industrial to domestic consumption : 43.9 %

- Ratio of administrational to domestic consumption : 19.2 %

b) Suburban area

Actual water consumption data of the sub-urban area is very small and it is impossible to estimate the planned value for the suburban area. For this plan, the proper value for the suburban area is estimated from the actual ratio of the urban districts. The actual ratio from 1999 for non-domestic to domestic water consumption in the 7th January and Chamcar Morn district where human activity is supposed to be similar to the suburban area is adopted for the suburban area. For reference, water consumption of administration use in the Don Penh district is relatively large because there are many administration offices in the district. Commercial and industrial water consumption in Toul Kork district is relatively small because there are little commercial and industrial activity in the district.

- Ratio of commercial and industrial to domestic consumption : 43.5 %
- Ratio of administration to domestic consumption : 16.1 %

7) Wholesaler demand

The water supply by wholesalers will be replaced by the PPWSA water supply and is expected to be disappeared in 2005.

8) Planned effective water ratio (EWR)

The planned effective water ratio is set as the same as the revenue water ratio planned by PPWSA in Table 2-2-12. This plan looks ambitious but judging from the past performance of PPWSA for the revenue water ratio improvement, PPWSA has ability to achieve the targets.

Table 2 - 2-12 Planned Effective Water Ratio

(unit:%)

Year	1992	1999	2000	2005	2010	2015
Planned effective water ratio			65	80	80	80
Actual ratio (%)	20	51	62 (1st qt.)			

9) Daily maximum coefficient (or Peak factor)

The daily maximum coefficient (daily maximum demand/average maximum demand) indicates seasonal fluctuation of water demand. Generally, this coefficient is lower for larger city or for the area that has smaller fluctuation of annual temperature. For example it is 1.21 for Sapporo, 1.19 for Tokyo, 1.12 for Okinawa in Japan, Bangkok (1.1~1.4) and Jakarta (1.3). The daily maximum coefficient for the Phnom Penh city shall be planned as 1.3 referring to the values of Bangkok and Jakarta. Currently, PPWSA also uses 1.3 as the design value.

10) Result of water demand forecast

Results of the water demand forecast in the Phnom Penh city is tabulated in Table 2-2-13 and appendix.

Table 2 - 2-13 Water Demand Forecast for Phnom Penh City

Year	2000	2005	2010	2015
Total population (1,000 people)	1,040	1,342	1,722	2,201
Urban	553	653	760	871
Suburban	487	689	962	1,330
Planned served population (1,000 people)	332	739	1,175	1,611
Urban	330	653	760	871
Suburban	2.5	86	415	740
Planned service rate by the PPWSA (%)	32	55	68	73
Urban	59.6	100	100	100
Suburban	0.5	12.5	43.2	55.6
Planned per capita consumption(Domestic)				
Urban	132	132	132	132
Suburban	100	100	100	100
Planned per capita consumption (Whole use)	204	195	182	176
Urban	204	201	201	201
Suburban	197	146	146	146
Planned effective water ratio (or revenue water ratio)	65	80	80	80
Daily average water demand (m^3/day)	104,000	180,000	267,000	354,000
Urban	103,000	164,000	191,000	219,000
Suburban	1,000	16,000	76,000	135,000
Daily maximum water demand (m^3/day)	135,000	234,000	347,000	460,000
Urban	134,000	214,000	248,000	285,000
Suburban	1,000	20,000	99,000	175,000

11) Recommendation for water demand forecast

Population forecast and water demand has been computed here, but there are still some unforeseen elements concerning future population increase. Moreover, the framework for city development, i.e. infrastructure development plans including public water supply, has not yet been consolidated. Therefore, trends in future water demand contain some uncertain elements. By 2005, which is the completion time of the Project, it is believed that the trend of population increase and development will be settled. It will be necessary at that time to revise the water supply Master Plan including water demand forecast, and redefine the future direction of water supply facility plan for the Phnom Penh city.

2 - 2 - 3 Basic Plan

(1) Scale of Expansion of Water Treatment Plant

The existing total water production capacity of the Phnom Penh city is 120,000 m^3/day. In 2001, Chrouy Changwar WTP (65,000 m^3/day) is planned to be commissioned and the total water production capacity will increase to 185,000 m^3/day. The expansion scale of the Phum Prek WTP for the Project shall be 50,000 m^3/day to meet the water demand in 2005. As shown in Table 2-2-14, the total capacity of water treatment plants of the Phnom Penh city will be 235,000 m^3/day in 2005, which can meet the maximum water demand in the Phnom Penh city of 234,000 m^3/day in 2005. Fig. 2-2-2 shows the water demand forecast and expansion plan of water treatment plants. The expansion plan after 2005 is based on the PPWSA plan.

Table 2 - 2-14 Planned Water Production Capacity until 2005 for Phnom Penh City

(unit: m^3/day)

Name of WTP	Existing capacity	Capacity in 2005	Planned year of commencement
Phum Prek	100,000	150,000	2004 (this project)
Chamcar Morn	20,000	20,000	-
Chrouy Changwar	-	65,000	2001
Total	120,000	235,000	-

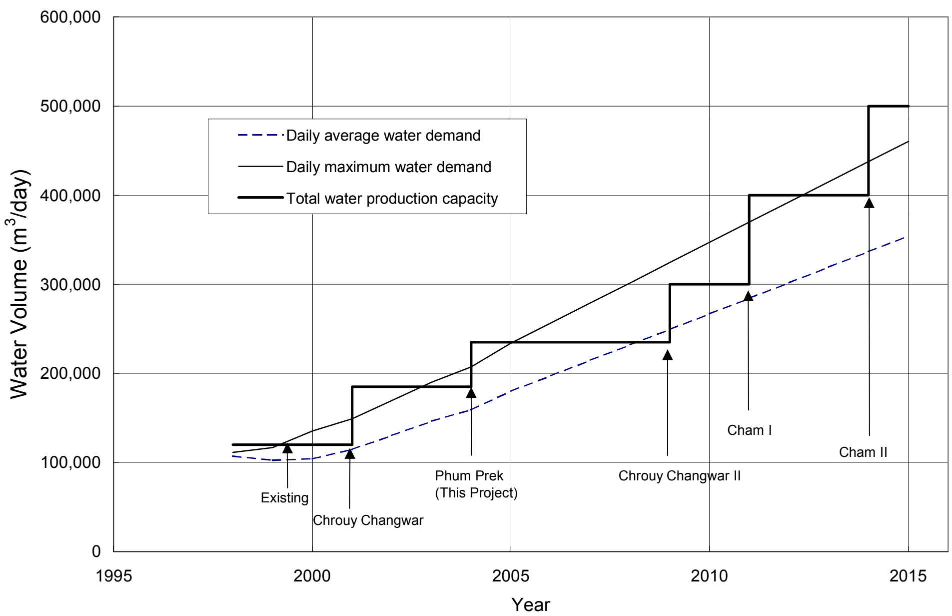


Fig. 2 - 2-2 Water Demand and Total Production Capacity

(2) Total Capacity of Phum Prek Water Treatment Plant

The production capacity of the existing Phum Prek WTP is 100,000 m^3/day. If the expansion capacity of 50,000 m^3/day is added, the total capacity of the Phum Prek WTP after completion of expansion will become 150,000 m^3/day. If the water required in the plant for miscellaneous work such as washing the facilities is added, the required water treatment capacity becomes 158,400 m^3/day (1.056 times the supply capacity) as mentioned in 2-2-4 (2).

(3) Intake Pump Equipment

1) Status of existing pump equipment and required measures

The intake and raw water main system consists of 3 pumps in the intake tower on the shore of the Tonle Sap and 2 raw water mains (approximately 1.3 km) installed between the intake and the WTP. This system is used to convey the raw water from the river to the WTP. Three intake pumps of the specifications given below have been installed in the existing intake tower.

Type: Vertical mixed flow pump
Flow rate: 2,200 m^3/hour
Total head: 21.0 m
Motor output: 3000 V, 185 kW
Number of pumps: 3 (including 1 standby)

All three pumps satisfy the design lift and are currently in operation. However, the design flow rate is not being achieved. Detailed studies of the functions of intake and raw water mains have been carried out by an Australian consultant during the period of 1997 to 1999. The findings of the studies by the JICA Study Team in July 2000 based on measured values (intake water level, intake pump gauge pressure and raw water conveyance quantity) showed that the report issued by the consultant was reliable. Accordingly, the consultant's study report has been used in this JICA Study as a reference.

In the consultant's study, the pump system curve (flow rate versus gauge pressure curve) of the pump system was determined when one, two and three intake pumps were operating in parallel. Table 2-2-15 shows the comparison of the nominal capacity of intake pump and the actual pump capacity calculated from the pump system curve.

Table 2 - 2-15 Comparison of Nominal Capacity and Actual Capacity of Intake Pump

Item	Unit	River water level (planned water level)		
		＋1.5 m (low water level)	＋5.0 m	＋11.0 m (high water level)
Nominal capacity (2-pump operation)				
Flow rate	m^3/hour	4,400	5,000	5,400
Water pressure	m	21.0	18.1	15.3
Power consumption	kWh/m^3	0.073	0.063	0.056
Capacity during actual operation (2-pump operation)				
Flow rate	m^3/hour	3,640	4,150	4,750
Water pressure	m	22.8	22.0	19.7
Power consumption	kWh/m^3	0.086	0.077	0.067
Capacity during actual operation (3-pump operation)				
Flow rate	m^3/hour	3,890	4,410	5,240
Water pressure	m	24.0	23.5	22.9
Power consumption	kWh/m^3	0.113	0.101	0.088

Source: Brisbane City Enterprises & ACTEW Corporation Ltd., Australia. March 1999, "Energy Audit & Energy Management Plan."

Although the required intake water rate can be normally ensured by two-pump operation when the water level of the Tonle Sap is at the design low water level, in practice, the intake water rate of 3,890 m^3/hour (93,360 m^3/day) cannot be achieved by even three-pump operation. Low water level occurs during the summer when the demand for water is the highest. A decrease in the quantity of raw water during this season considerably affects the supply of water to the Phnom Penh city.

In the same study mentioned above, the coefficient (C) of flow velocity of existing raw water main was calculated by using the best-fit curve of actually-measured raw water quantity and pump gauge pressure. The results of the calculation showed that the coefficient of flow velocity of the raw water mains was about 70. Accordingly, the design flow rate of the intake pump cannot be ensured currently because of the very high friction loss of the raw water main that considerably exceeds the design value. (Note: C refers to the coefficient of flow velocity in the Hazen-Williams formula.)

The design volume of raw water cannot be conveyed to the WTP mainly because of the deterioration of the raw water main mentioned above and also in detail in the next section

2-2-3 (5). In addition, however, the decrease in the capacity of the pump itself has also contributed to the inability to meet design requirements. It was not possible to dismantle the pumps and perform a detailed study on the status of internal parts because no spare parts were available. However, the JICA Study Team has arrived at the conclusions as below regarding the status of the pumps from highly turbid water of the Tonle Sap, maintenance condition of the pumps, pump structure etc.

- Existing pumps do not have a protective tube for the main shaft. The sleeve bearings of the intermediate and lower part of the pump shaft are being lubricated by the river water itself. If water from the Tonle Sap that contains considerable silt is used as direct lubrication, considerable wear of the bearings and sleeves must have occurred.
- No abnormalities in particular were detected during external inspection of the motor. However, considerable wear of internal parts such as casing and impeller are anticipated, judging from the quality of the highly turbid raw water.
- Spare parts have not been used since the installation of the pumps in 1989.
- No spare part has been supplied since the commencement of the operation and spare parts are not available. (Note: Spare parts are expensive; their cost is almost the same as the cost of a new pump unit.)
- Existing pumps were installed in 1989 and 11 years have already elapsed. The impeller in the pump is made of bronze and its service life is about 15 years. An impeller made of stainless steel, on the other hand, has a service life of about 20 years. Thus, the service life of the existing pumps will be reached in around 2005.

In view of the conditions mentioned above, the performance of the intake pump is likely to deteriorate in the near future. When the expanded WTP becomes operational in 2004 (scheduled), there is a risk that the required rate of raw water will not be ensured. Accordingly, when the service life of the existing pumps is reached in around 2005, renewal of the pumps is necessary.

2) Intake pump plan for the expansion

When the Phum Prek WTP would be expanded, 158,400 m^3/day (6,600 m^3/hour) of raw water would be withdrawn from the intake and conveyed to the plant. The total capacity of 2 existing pumps is 4,400 m^3/hour and they can convey the raw water at the rate of 105,600 m^3/day. Additional capacity (2,200 m^3/hour) is required to ensure the required quantity of raw water for the expansion of the WTP.

The three alternatives for the number of new pumps mentioned below are considered in relation to the renewal of the existing intake pumps. (Fig.2-2-3)

Alternative A: Install 4 new pumps

If the plan envisages total flow of the raw water to the existing and expanded WTP, renewal of the 3 existing pumps and installation of 1 new pump are necessary.

(Existing pump) Disposed of

(New pump) 2,200 m^3/hour x 4 pumps (including 1 standby). Total capacity when in operation is 6,600 m^3/hour

Alternative B: Install 3 new pumps

Three (3) new pumps are installed to ensure the intake capacity (6,600 m^3/hour =158,400 m^3/day) for delivering water at the existing and expansion capacity of the WTP.

(Existing pump) Used as standby

(New pump) 2,200 m^3/hour x 3 pumps. Total capacity when in operation is 6,600 m^3/hour.

Alternative C: Install 2 new pumps

3 existing pumps (including 1 standby) are used for delivering water (4,400 m^3/hour) to the existing WTP. Two (2) new pumps (1 operational and 1 standby) are used for delivering water (2,200 m^3/hour) at the expansion capacity of the WTP.

(Existing pump) For existing WTP 2,200m^3/hour x 3 pumps (including 1 standby). Total capacity when in operation is 4,400 m^3/hour.

(New pump) 2,200 m^3/hour x 2 pumps (including 1 standby). Total capacity when in operation is 2,200 m^3/hour.

The results of technical and initial cost comparison for the three alternatives are shown in Table 2-2-16.

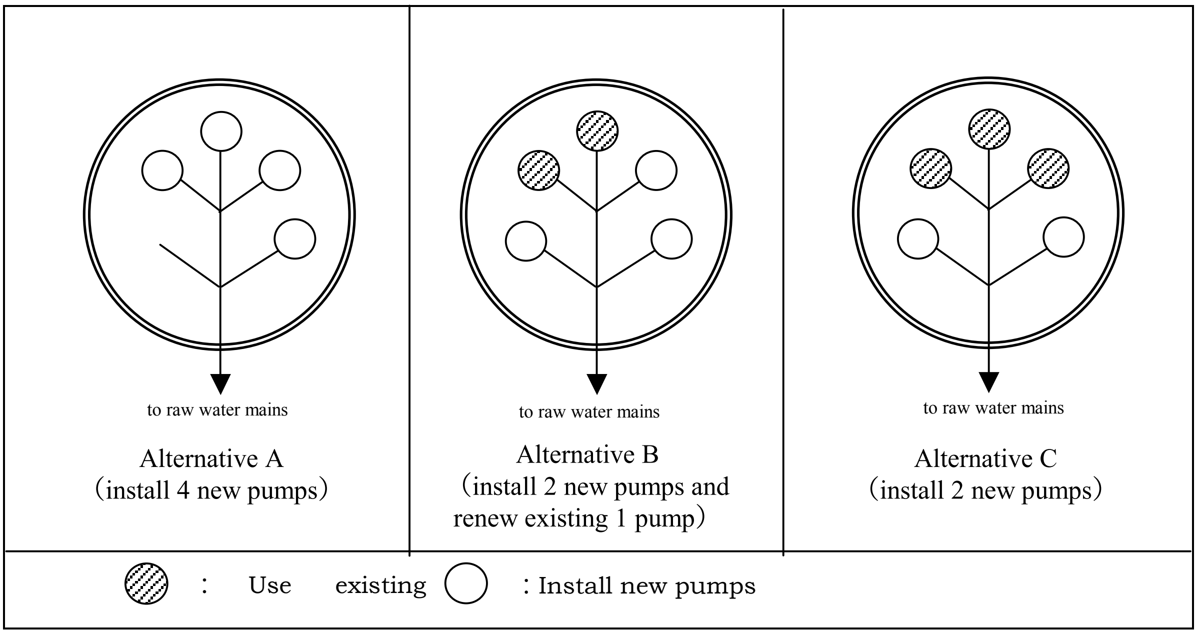


Fig. 2 - 2-3 Alternatives for Intake Pumps in Existing Intake Tower

Table 2 - 2-16 Technical and Cost Comparison of Intake Pump Alternative

	Alternative A	Alternative B (Adopted)	Alternative C
Technical evaluation	- All pumps are newly installed, which is the best alternative to ensure the required capacity including 1 standby.	- Three pumps are newly installed, which ensures the required capacity (158,400 m^3/day). - Disadvantage is no new pumps for standby. The existing 2 pumps are used as standby - The service life of existing pumps can be extended. - Even if all the existing pumps malfunction, the necessary capacity is ensured but there is no standby.	- Two pumps are newly installed, which account for only 2/3rds of the required capacity. At least one of the existing pumps should be in operation. - If all the existing pumps malfunction, it is not possible to ensure the required capacity (158,400 m^3/day).
Initial cost (Ratio)	2 (highest)	1.5	1 (lowest) Base cost

Alternative B is adopted for the plan of new intake pumps based on the following reasons.

- Ensure the necessary capacity (158,400 m^3/day) using new 3 pumps.
- Use existing pumps at maximum
- Save on the initial installation cost

(4) Raw Water Main Plan

1) Status of raw water mains and required measures

Presently, two cast iron pipelines of diameter 700 mm and length 1,300 m approximately without internal lining are being used between the intake pump and the WTP. These existing raw water mains were installed in 1958 and 1966.

According to the studies by the Australian consultant, flow coefficient (C) of the raw water mains is 70, which indicates deterioration of the pipelines. The findings of the studies on the intake/raw water main system by the JICA Study Team showed that the value of 70 for the raw water main is a rational value based on actually measured values (intake water level, intake pump gauge pressure and raw water quantity). Moreover, considering that 42 and 34 years respectively have elapsed since the installation of the pipelines and the fact that the pipelines do not have an internal lining, rust layers are likely to have formed on the internal surface of the pipeline with silt adhering to the rust layers. Therefore, it may be concluded that the flow coefficient is very low. For reference, an example of the variation with time of the flow coefficient of cast iron and steel pipeline is shown in Table 2-2-17.

Table 2 - 2-17 Example of Changes with Time of the Flow Coefficient of Pipes

Type of pipe	Coeff. of flow velocity（C）
Ductile iron and steel pipes	
New pipe	120
10 years	110
15years	100
20 years	90
30 years	80
50 years	70
70 years	60
New mortar-lined cast iron pipe	130

Source：Croker. Piping Hand book

The JICA Study Team visually examined the status of the internal part of the raw water main at the front end of the WTP after emptying the raw water receiving well of the WTP. The examination showed the existence of rust, but the status of rust was not as much as to indicate a flow coefficient of 70. However, silt deposits of about 15 cm were confirmed within the raw water main. It is therefore concluded that the coefficient of flow velocity was judged as 70 because of the rust and silt deposits that reduce the cross section of the mains.

Table 2-2-18 shows the results of calculations of the flow coefficient of the raw water mains at low water level of the Tonle Sap for two cases: Case A assuming no silt; and Case B assuming 15-cm silt deposits. Fig. 2-2-4 shows a schematic sketch of the head loss in the intake/raw water main system. From the calculations, the coefficient of flow velocity for Case B assuming 15-cm silt deposit was estimated as approximately 88. This value indicates that the pipes are required to repair or renew although it is better than the earlier value of 70. The findings of the Australian study mentioned earlier also ranked the renovation of existing raw water mains as the first priority project of other projects in the WTP.

Table 2 - 2-18 Study on the Functions of Raw Water Mains at Low Water Levels of the Tonle Sap

	Unit	Case A No silt	Case B 15-cm silt
Calculation conditions			
Effective bore（D）	m	0.7	0.643
Length of raw water main（L）	m	1242	1242
No. of raw water mains	-	2	2
Head loss after pump	m	1.1	1.1
Head loss of raw water main（H）	m	9.2	9.2
Calculation results			
Coefficient of flow velocity（C）		70.1	87.7

Note: Calculated for low water level condition. (Intake pump head 24 m, raw water flow rate 93,360 m^3/day=3890m^3/hour（from system curve of intake pump made by the Austrarian consultant))

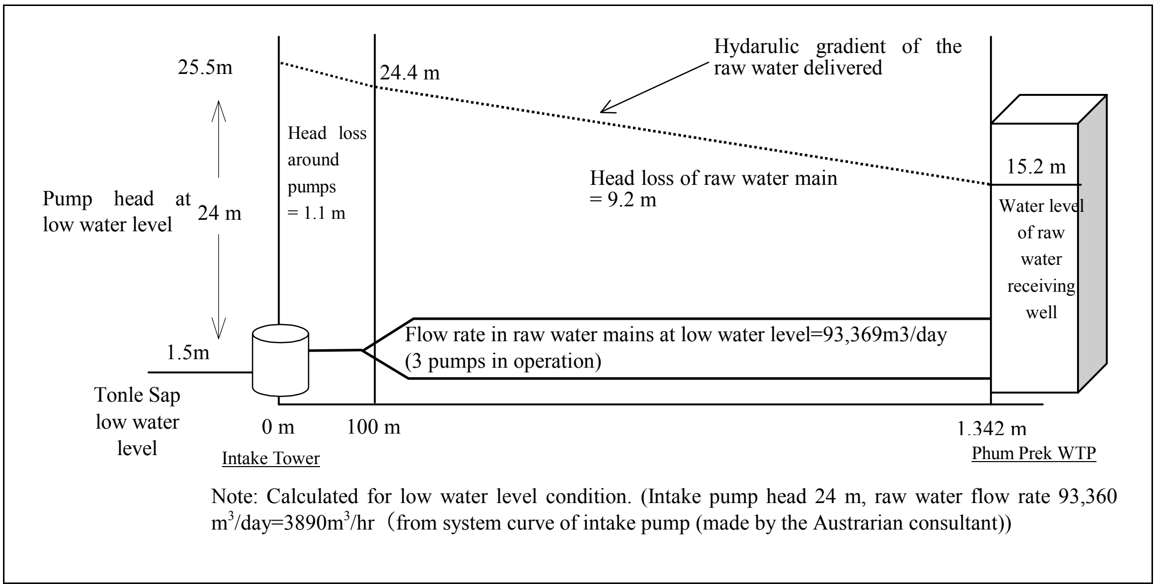


Fig. 2 - 2-4 Head Loss and Hydarulic Gradient of Raw Water Intake at Low Water Level of the Tonle Sap

2) Study on the raw water mains for the expansion of facilities

Two existing raw water mains were designed based on flow coefficient of 100, and delivery capacity of 105,600 m^3/day at the low water level in Tonle Sap. However, the present actual delivery rate is 70 percent of the nominal capacity due to deterioration. The raw water main is planned so that it can deliver the necessary quantity of raw water (158,400 m^3/day) to the expanded WTP, by considering the shortfall in capacity of the existing mains.

The three Alternatives mentioned below were compared for the raw water main plan. (Remarks: The diameter of the raw water main to be newly installed is studied in 2-2-4 (7).)

Alternative A: Use existing raw water mains as-is, and compensate for the shortfall in the capacity of existing mains by increasing the capacity of the raw water mains to be newly installed.

Alternative B: Don't use existing raw water mains. Compensate the capacity of existing mains by increasing the capacity of raw water mains to be newly installed.

Alternative C: Use existing raw water mains after renovation (cleaning and installing lining on the internal surface), and compensate for the shortfall in the capacity of existing mains by increasing the capacity of raw water mains to be newly installed.

From the three alternatives mentioned above, Alternative C was removed from the scope of the study since its adoption was impractical due to the reasons mentioned below.

- Renewal costs are considerably high because Cambodia does not have the technology required for the renovation.
- The WTP has to be shut down for a long period to modify
- Since lead caulking is used in the connections of the existing water mains, the impact that occurs when removing rust is likely to cause damage and leaks
- There is no manhole for renovation works

Table 2-2-19 shows a comparative study of Alternative A and B. Based on the study, Alternative B is adopted for the raw water plan.

Table 2 - 2-19 Study of Alternatives for the Raw Water Main Plan

	Alternative A	Alternative B
Description	Use existing raw water mains (flow coefficient C=70)	Don't use existing raw water mains. Use new main installed as standby.
Installation of new raw water main	Dia 900 mm ~ 1000 mm x 1 set (C=130) About 1550 m	Dia 1200 mm x 1 set (C=130) About 1550 m
Condition of existing raw water mains in the future	・ Pipe deterioration will be increase further in the future since no lining is provided on the internal surface of the main ・ Silt deposition will increase further ・ Service life of the raw water main has almost been reached	
Pump operation	Complicated	Normal
Approx. construction costs	Taken as 1	About 1.3
Problems	・ Pump operation is complicated ・ The existing pipe is used for more than 40 years. Service life of cast iron pipes with no internal lining has almost been reached. ・ Water transmission functions of mains are likely to deteriorate further in the future.	・ Initial construction cost is approximately 1.3 times that of Alternative A
Evaluation	× Unsuitable because of various problems such as: completion of service life. Further deterioration of mains is anticipated in the future, which causes shortfall of delivry capacity and shortage of raw water at the WTP; and maintenance and operation are complicated.	○ Although initial cost is slightly higher, the following merits can be identified. ・ Very slow deterioration because new pipe has mortar lining. ・ Standby pipeline becomes available ensuring safety of the water supply system. ・ Periodic cleaning and inspections are possible because of the availability of a standby pipeline

Notes: Refer to Section 2-2-4(7) for information on the plan for installling new raw water main of dia. 1200 mm in Alternative B.

(5) Necessity of Equipment for Anti-Water Hammering

Water hammering occurs in a pump and transmission system when the pump stops suddenly because of power failure or other reasons. This results in water column separation or abnormal pressure variation. When the water hammering pressure exceeds the allowable value of strength of pump or pipeline, severe damage may occur to the pump equipment or the pipeline. Equipment for preventing such damage needs to be installed in the pump and transmission system.

Water hammering analysis was carried out assuming power failure had occurred during normal operation of intake pump after expansion of the facilities. Table 2-2-20 shows the analysis results based on assumptions as given below.

Calculation assumptions: 3 intake pumps in operation (discharge flow rate 2,200 m^3/hour x head 21 m)

: Raw water main (dia. 1,200 mm x length 1,550 m)

: Since the raw water main is newly installed, the head loss initially is assumed to be low at about 5%. (Discharge flow rate: 38.7 m^3/min. x head: 19.6 m (per pump))

Table 2 - 2-20 Water Hammering Analysis

Unit: m above the base level

	Position of raw water main from intake tower (m)				
	0	400	800	1200	1600
Installed position of raw water main	12.8	9.0	9.0	9.0	9.0
Steady state water level	21.0	19.25	17.5	15.75	14.0
When water hammering occurs					
Maximum water level	25.8	23.2	22.0	20.6	14.0
Minimum water level	- 1.6	- 2.8	- 2.8	- 0.8	14.0

Base level: +1.46 m (Planned low water level in the intake tower)

As shown in the table above, negative pressure occurs over the entire pipeline during the water hammering, which leads to water column separation in the raw water main. Accordingly, equipment for preventing water hammering is necessary.

The existing pressure tank (air vessel) for preventing water hammering is installed on the shore of the river adjacent to the access bridge of the intake tower. Since this tank is partially embedded in the ground, water enters the tank chamber at high water levels during floods. Consequently, the bottom part of the steel pressure tank has corroded, and its performance as a pressure vessel has deteriorated. Equipment for preventing water hammering is planned to be renewed.

(6) Water Treatment Facilities

1) Status of existing water treatment facilities and required measures

Table 2-2-21 gives the summary of the status of existing water treatment facilities, their problems and the required measures.

Table 2 - 2-21 Problems of Existing Water Treatment Facilities and Required Measures

Facility	Problems	Measures
Water treatment facilities (Coagulation, sedimentation, filtration)	• Retention time for rapid mixing is inadequate (presently 30 seconds, need more than one minute) • Retention time for slow mixing is inadequate (presently 17 minutes, need more than 20 minutes) • Sedimentation efficiency is poor because of the aging of chemical feeding equipment and structural defects in the inlet of the chemical sedimentation basin. Turbidity after sedimentation reaches high levels of 10 to 30 NTU causing excessive loads on the filter. • Many cracks have been found in the sedimentation basin. • Capacity of rapid filter is unsatisfactory.	• Ensure appropriate retention time. • Baffle wall should be provided in the inlet of the sedimentation basin for improving sedimentation efficiency • There is a risk of structural collapse due to cracks. Cracks need to be repaired.
Chemical feeding equipment (Coagulant feeder - 3 machines) (Slaked lime feeder - 2 machines) (Chlorine feeder - 2 machines; of which 1 feeder already removed and disposed of)	• Excessive aging of chemical feeding equipment • 1 coagulant feeder is non-functional. Flow adjustments cannot be made in the two remaining feeders that are operational. • Equipment for feeding slaked lime, which is a pH regulator (increases the pH value), was shifted from the Chamcar Morn plant, and temporary operation has begun. Since piston-type equipment is used, it is likely to fail when currently-used chemicals are used. Slaked lime should be added to the raw water receiving well and to water after filtration. However, in the existing system, it is added to the water before filtration and should be added to raw water receiving well in order to improve the coagulating effect. • Only 1 chlorine feeder is operational. There are no chlorine neutralizing equipment, moreover, the chlorine gas cylinders are installed in a room that is exposed outside the room. Currently, maintenance of these equipment is very dangerous. In the past, there have been cases of chlorine leakage.	• Since the aging of all the equipment is excessive, all the equipment needs to be renewed/ rehabilitated.
Water treatment process	• The intake flow fluctuates considerably due to the fluctuation of water level of the water source and the fluctuation will be made even within a day due to difficulty of the intake pump operation. It is very difficult to perform correct settings of chemical feed volume. Moreover, since there is no feed of slaked lime, it is very difficult to control water treatment process.	• The intake flow volume needs to be controlled. • The chemical feed quantity needs to be correctly controlled.

2) Studies on the new chemical feeding facilities

a) Study on the chemical feeding equipment for existing and new water treatment facilities

In addition to installation of new chemical feeding equipment for the new water treatment facilities to be expanded, the existing chemical feeding equipment should be repaired or renewed. In view of the reasons mentioned below, existing chemical feeding equipment should be disposed of without repair or renewal and the capacity of the chemical feeding equipment disposed of should be included in the capacity of the expanded chemical feeding equipment. This will enable a single system of chemical feeding equipment to be used for both existing and expanded water treatment facilities.

- By adopting a single feeding system, installation cost can be reduced.
- By adopting a single feeding system, maintenance and operation costs will be lower than that of dual system
- By adopting a feeding single system, maintenance and operation become easier than that of dual system.
- By adopting the gravity system (refer to Section 2-2-4(11)) for new chemical feeding equipment, maintenance and operation will become easier and its costs are lower, moreover, few breakdowns will occur.

b) Study on the construction of new chemical building

The aging of the existing chemical building is excessive and its repairs will be very expensive. Moreover, there is no space in the existing chemical building to install chemical feeding facilities for the expanded water treatment facilities. Therefore, a new chemical building should be constructed that contains the chemical feeding equipment required for both existing and expanded water treatment facilities.

c) Study on water quality analysis laboratory

The ability to analyze and monitor water quality should be enhanced in order to improve the quality of treated water. The size of the existing water quality analysis laboratory is about 9 m^2. The existing building does not have space to accommodate equipment required for carrying out proper water quality analysis. Moreover, most of the existing water quality analysis equipment are portable type and can be used only for simple analyses.

The water quality analysis laboratory of the Phum Prek WTP is not only the main laboratory of the Phnom Penh city but also for whole Cambodia. Water quality analysis of local water supply authorities of other parts of Cambodia is conducted in this laboratory. Such a laboratory needs to have adequate space for installing substantial equipment for water quality analysis.

The improvement of the treated water quality of the expanded water treatment plant is essential for the project. To do so, the improvement in the capacity of water quality analysis and monitoring is required.

JICA dispatched an water quality analysis expert from Japan Overseas Cooperation Volunteers (JOCV) to Phum Prek WTP for improving the capacity of PPWSA in analysis and monitoring of water quality in the water supply system. However, the analysis and monitoring level is not improved enough due to the lack of proper analysis equipment.

Under the above conditions, a new water quality analysis laboratory is planned to be established in the expanded WTP to improve water quality of the water supply system.

The chemical building should be a two-story building since the new chemical feeding equipment to be installed will be gravity-type equipment (refer to 2-2-4(11)). Therefore, this new chemical building will have an extra-space that can be used. This space can be used to set up the new water quality analysis laboratory.

For this plan, general analysis equipment required for the ordinary analysis of quality of water in the WTP should be installed. Adequate space should be reserved so that the analysis equipment can be upgraded in the future to upgrade the level of water quality analysis.

3) Study on the installation of new raw water receiving well and rapid mixing basin

To ensure a trouble-free system that can be maintained and operated easily for the rapid mixing basin after its expansion, the method of rapid outflow from the raw water main without using any equipment, and the rapid agitating method using water level difference in the weir should be adopted (refer to 2-2-4(10)). Therefore, the raw water receiving well and the rapid mixing basin should be constructed as an integral facility.

Alternatives for using (Alternative A) and not using (Alternative B) the existing raw water receiving well and rapid mixing basin were considered. Fig. 2-2-5 shows a schematic sketch of these two Alternatives.

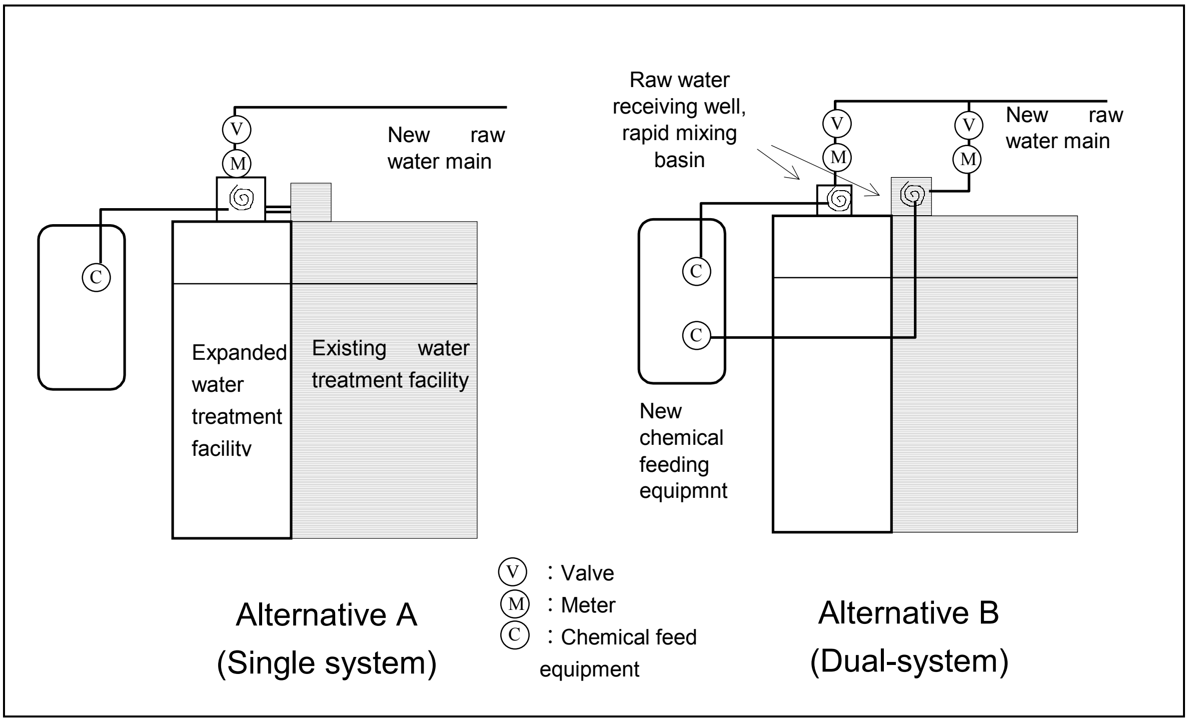


Fig. 2 - 2-5 Alternatives for Raw Water Receiving Well and Rapid Mixing Basin

The existing facilities will not be used in this plan because of its disadvantages as mentioned below. As a result, the Alternative A is adopted for the plan and one new basin is constructed that includes the raw water receiving well and the rapid mixing basin for the existing and the new water treatment facilities.

- If existing facilities are used, two systems for chemical feeding, valves and flow meter equipment will be required and the maintenance and operation of the facilities will become complicated. The maintenance and operation costs of two systems are higher than that of a single system.
- If the existing facilities are used, the costs of equipment for two systems, namely the existing and expanded facilities, will be greater than the construction costs of a single system in which the new raw water receiving well and the rapid mixing basin are shared.
- The retention time of the existing rapid mixing basin is small (30 seconds), therefore, mixing is unsatisfactory. Thus if the existing rapid mixing basin is used, it is be difficult to improve treated water quality of the existing water treatment facility.

4) Flocculation basin

The retention time of the existing flocculation basin is only 16 minutes against more than 20 minutes, which is normally required. Therefore, slow mixing is not adequate for coagulation and treated water quality cannot comply with the WHO standards. However, it is difficult to increase the retention time by adding a flocculation basin to the existing ones; therefore, the existing facilities should be used as-is.

The shortage in retention time is 4 minutes, which is equivalent to 4,800 m^3/day. This shortage is planned to be covered by the expanded flocculation basin. As a result, the capacity of the expanded flocculation basin becomes 57,600 m^3/day and that of the existing one is 108,000 m^3/day (refer to 2-2-4(8) and (9) for details).

5) Chemical sedimentation basin

a) Expansion

The capacity of the expanded flocculation basin is planned at 57,600 m^3/day and that of the existing one is at 108,000 m^3/day (Refer to Section 2-2-4(8) and (9) for detail).

b) Existing

The problems in the existing chemical sedimentation basin are as given below.
① Many cracks exists
② Flow velocity is high
③ Structure of sedimentation basin is inadequate

The structure of the inlet of the sedimentation basin is as shown in Fig. 2-2-6. This structure is likely to cause stirring up of the settled sludge at the inlet of the sedimentation basin. Moreover, since no baffle wall has been provided, the portion of the stirred settled sludge can’t be considered as surface load area. As a result, defects such as turbulence, short-circuit in flow and dense flow occur in the entire sedimentation basin. These defects hampers the sedimentation of the turbidity components and lower the quality of the treated water.

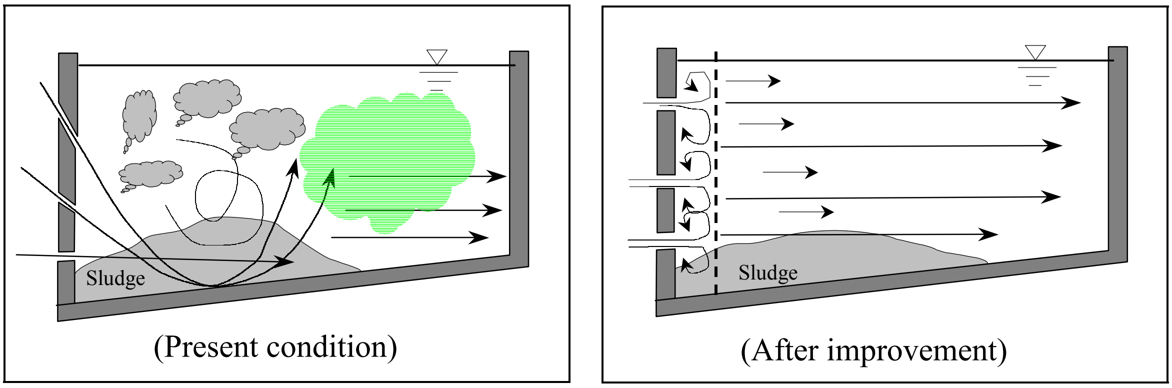


Fig. 2 - 2-6 Structure of the Sedimentation Basin

For proper functioning of the existing sedimentation basin and improved quality of treated water, the structure of the inlet should be changed and baffle walls should be installed in the inlet and intermediate parts. Accordingly, for this plan, the structure of the inlet is to be changed and baffle walls are to be installed in the inlet part of the sedimentation basin. The figure on the right in Fig. 2-2-6 shows the improved structure of the existing sedimentation basin.

6) Rapid filter

The required capacity of the existing rapid filters including the treated water required for work in the plant is 105,600 m^3/day, but the design capacity is 100,000 m^3/day. The shortage in filtration capacity should be covered by the expansion of rapid filter of the new water treatment plant.

(7) Distribution Reservoir Capacity

1) Analysis of water distribution status in the water supply areas

PPWSA has divided the city into water distribution zones with the aim of controlling water leakage by estimating the distribution volume within each zones. The data given below was used for the analysis of water distribution status in the city. Measured data of distribution volume per hour is available for 21 distribution zones. Table 2-2-22 shows the summarized analysis data, time coefficient, required storage time and other calculated results for each district.

Table 2 - 2-22 Analysis of Water Distribution Status for Each District

District	No. of distribution zone where distribution quantity is measured	Date of measuremnt	Total distribution volume per day in districts	Average distribution volume per hour in districts	Time coefficient (max. hourly flow / average hourly flow	Required capacity of distribution reservoir	Required storage time
	No.	-	m^3/day	m^3/hour	-	m^3	Hours
7th January	8	2/15~3/1	10,525	438.5	1.49	2,038	4.65
Chamcar Morn	8	3/27~6/15	8,067	336.1	1.36	1,091	2.48
Don Penh	4	1/17,5/18, 9/14	9,093	378.9	1.37	1,319	3.48
Toul Kork	1	6/26	977	40.7	2.06	193	4.74
Total for 21 zones	21	-	28,663	1,194.3	1.37	4,598	3.85

Note: The average distribution volume in 1999 was 111,000 m^3/day.
For detailed tables, refer to appendix.

The total measured distribution volume for all the 21 zones were 28,663 m^3/day. This figure is about 26% of the average total distribution volume per day (111,000 m^3/day). The time coefficient calculated from per hour flow of 21 zones was 1.37, while the required storage time was 3.85 hours. If the above results are to be used for analyzing the distribution status of all the areas in the city after the expansion of the facilities, then the points mentioned below should be considered.

a) Increase in supply pressure after expansion

The results mentioned above are based on the measured values of distribution volume in zones where the distribution pressure (0 to 10 m) was inadequate. After this project is implemented, the distribution pressure in the city will reach an appropriate value (greater than 25 m). As a result, the supply of water during the daytime will increase, and the required storage time is expected to be greater than the measured value.

b) Analyzed distribution volume and total distribution volume in the city

Only some parts of the whole city area were measured and analyzed for distribution volume. The analyzed distribution volume was 24% of the total distribution volume of the city. Generally, as the size of the city increases, water has to be supplied to diverse users. The distribution volume per unit time is averaged out, and there is a tendency for the time coefficient and the required storage volume to decrease. Considering the above points, the time coefficient and required storage time for the total distribution volume of the entire city are estimated to be smaller than the values given by these results.

c) Analysis by zone

The water supply condition in the 7th January district is considered to be far better compared to other districts. The time coefficient for this district is 1.49, while the required storage time is 4.65 hours. These values are greater than those for other districts. The Chamcar Morn district is considered to have unsatisfactory water supply. Therefore, the time coefficient and storage time is low, but when the water supply pressure becomes appropriate, the time coefficient and the required storage time are anticipated to increase.

Based on an overall judgement of the points mentioned above, the time coefficient and required storage time for the optimum water supply status of the Phnom Penh city are considered to lie within the range mentioned below.

- Time coefficient: 1.4 to 1.5
- Required storage time: Greater than 4.0 hours of daily maximum distribution volume

2) Study on the distribution reservoir capacity

Results of analysis of the distribution volume per unit time show that the capacity of the distribution reservoir should be greater than a four-hour storage capacity. Four (4) hours are adopted in the plan. If the total maximum treated water supply capacity after expansion is taken as 150,000 m^3/day, and the above value is considered, the minimum required capacity of the distribution reservoir works out to be 25,000 m^3.
150,000 (m^3/day) x 4 (hours) / (24 hours/day) = 25,000 m^3

The existing distribution reservoir in the WTP has a capacity of 20,000 m^3. Thus, an additional capacity of 5,000 m^3 is required. If the capacity of elevated water tanks in the city is included (2,000 m^3), a storage capacity equivalent to 4.3 hours is available.

(8) Transmission and Distribution Pump Equipment

1) Status of existing transmission and distribution pumps and required measures

The treated water from the Phum Prek WTP is being distributed using 6 distribution pumps and 2 transmission pumps to areas within the city directly and through elevated water tanks.

Fig. 2-2-7 shows the arrangement and description of these pumps. Out of the 4 distribution pumps installed in the No. 1 pump room, 3 pumps (flow rate 2,100 m^3/hour, total nominal head 42 m) were obtained as aid from the French government in 1966, while the remaining one pump was obtained as part of aid from the UNDP in 1997.

The No. 2 pump room was constructed and pumping equipment were installed in 1995 under the Project for Improving the Water Supply Facilities in Phnom Penh (Phase I) with grant aid given by the Government of Japan (GOJ). The No. 2 pump room has four pumps (flow rate 1,050 m^3/hour, total nominal head 42 m) in which two are distribution pumps, while the other two are used as transmission pumps to the elevated water tank.

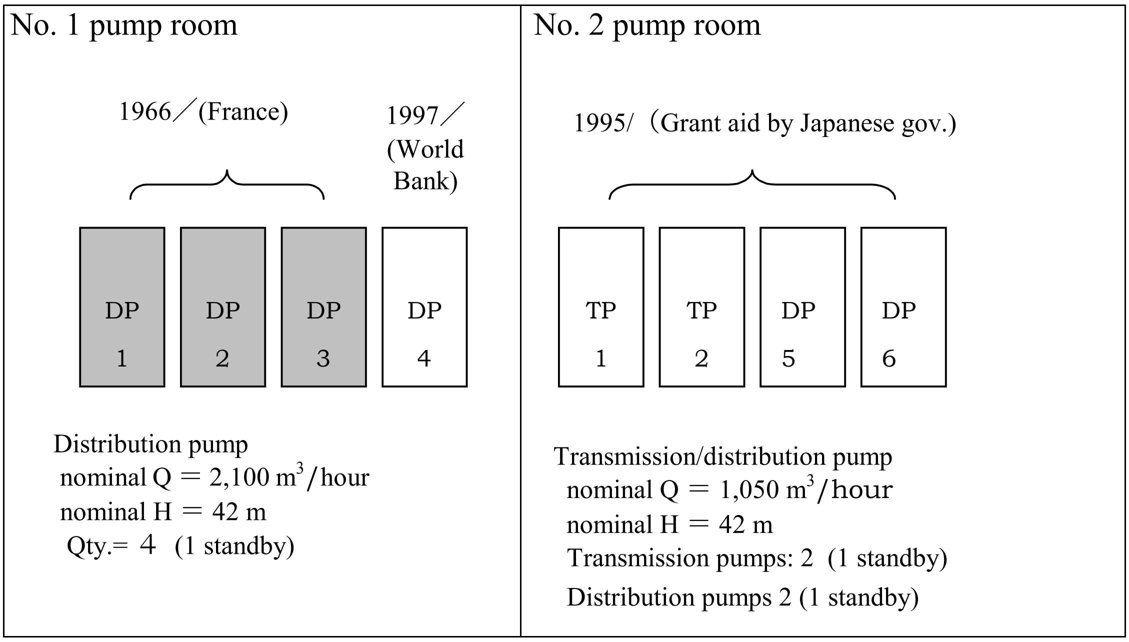


Fig. 2 - 2-7 Layout of Existing Transmission/Distribution Pumps

The Study Team measured the cut-off pressures of the pump to judge the performance of the existing pumps. The cut-off pressure is generally about 1.5 times the design head. In case of these pumps (design head 42 m), a cut-off head of about 63 m is required. Table 2-2-23 shows the cut-off head given in the existing literature and measured by the JICA Study Team.

Table 2 - 2-23 Cut-off Pressure Measurements

Pump	Cut-off head (m)		Design head (m)	Design flow rate (m^3/hour)
	JICA Study Team	JICA Experts		
Distribution pump 1 (DP1)	5		42	2100
Distribution pump 2 (DP2)	16	17.4	42	2100
Distribution pump 3 (DP3)	16		42	2100
Distribution pump 4 (DP4)	62	59.8	42	2100
Distribution pump 5 (DP5)	61	60.7	42	1050
Distribution pump 6 (DP6)	60	59.2	42	1050
Transmission pump 1 (TP1)	60	58.7	42	1050
Transmission pump 2 (TP2)	60	60.2	42	1050

Note: JICA Experts (Report on the Maintenance and Operation of Water Supply Facilities by JICA Expert. March 1999)

From the results of actual measurements, it was found that the three distribution pumps made in France and installed in 1966 were malfunctioning. The service life of the pumps is generally 15 to 20 years, and this service life of these pumps has been reached a long time ago. Therefore, they need to be repaired or renewed.

One pump of the same type and same age that required repairs/renewal was out of operation. The JICA Study Team dismantled the pump and inspected the internal parts. The impeller had worn out excessively, and rust was found almost in all internal parts. From the condition of the dismantled pumps, it was judged that the 3 pumps that need repair were also in similar condition, i.e., without the ability to reach the design head due to wear of impeller.

The malfunctioning of these three pumps results in low water supply pressure (0~10 m in head) in the city.

To improve water supply pressure, it was decided that all the 3 pumps need complete overhaul or renewal. However, spare parts of the pumps are not available because these were manufactured 35 years ago and the supplies of spare parts have stopped. Consequently, it was decided that these pumps should be renewed.

2) Study on the capacity of transmission and distribution pumps for the expansion

Under this plan, three existing pumps of 2,100 m^3/hour capacity installed in 1966 are to be renewed. In addition to the renewal, capacity of pumps required to ensure appropriate distribution volume per hour to the city after expansion of the WTP is studied. The time coefficient is taken as 1.4 in the study (refer to 2-2-3 (7)).

A flow rate greater than 1.4 times the average distribution volume per hour of the maximum daily distribution volume (greater than 8,750 m^3/hour) should be distributed from the WTP.

- Average distribution flow per hour of the maximum daily distribution volume: 6,250 m^3/hour (=150,000 (m^3/day) / 24 (hours /day))
- Maximum distribution volume per hour: 8,750 m^3/hour (6,250 m^3/hour x 1.4)

During Japan's grant aid project (phase I) of 1995, space was reserved for the installation of one pump in the No. 2 pump room, and provision was made for installing electric equipment with a capacity to run a distribution pump of 1,050 m^3/hour. Assuming that a pump of capacity 1,050 m^3/hour, the same capacity as the existing pumps in the No 2 pump room is installed, the distribution capacity is checked for the expanded WTP.

Table 2-2-24 shows the results of the check carried out. The table shows that the planned pump operation has the required hourly distribution capacity and also the capacity is equivalent to 1.46 times the hourly distribution volume of the maximum treated water volume (150,000 m^3/day = 6,259 m^3/hour) of the Phum Prek WTP. This capacity is also not excessive. Accordingly, the installation of one pump of capacity 1,050 m^3/hour is considered in the pump plan for the expansion of the facilities. The pump installation plan is shown in Fig. 2-2-8.

Table 2 - 2-24 Planned Pump Capacity

Pump	Total quantity	Quantity in operation	Design distribution volume per hour per pump	Total distribution volume per hour	Daily distribution volume
Distribution					
DP1~DP4	4 pumps	3 pumps	2100 m^3/hour	6300 m^3/hour	151,200 m^3/day
DP5, DP6 DP7 (this plan)	3 pumps	2 pumps	1050 m^3/hour	2100 m^3/hour	50,400 m^3/day
Total	7 pumps	5 pumps	-	8400 m^3/hour	176,400 m^3/day
Transmission					
TP1, TP2	2 pumps	1 pumps	1050 m^3/hour	1050 m^3/hour	25,200 m^3/day

Q_{max} = 8400 + (1050/1.4) = 9150 m^3/hour ≧ 8750 m^3/hour OK
(Distribution) (Transmission)

9,150 m^3/hour / 6,259 m^3/hour = 1.46 > 1.4 (time coefficient)

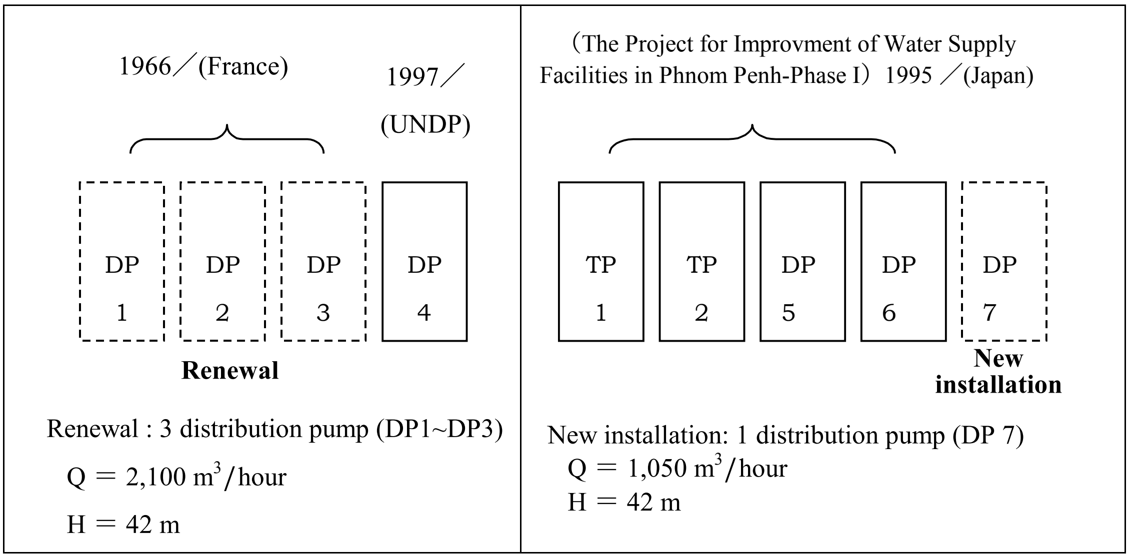


Fig. 2 - 2-8 Transmission and Distribution Pump Plan

2 - 2 - 4 Facility and Equipment Plan

(1) Overview of Facility and Equipment Plan

In the following part, detailed studies were carried out to decide the detailed plan (specifications, layout, capacity, route etc.) of the planned facilities and equipment. Table 2-2-25 gives an overview of the facility and equipment plan.

Table 2 - 2-25 Overview of the Facility and Equipment Plan

Facility plan	Facilities/equipment in this plan	Contents of plan/design
Basic capacity plan	Expansion of facilities by 50,000 m^3/day	・ Planned capacity of major facilities
General layout plan of facilities		・ Raw water main route ・ Layout of water treatment facilities
Facility water level plan		・ Water level of each facility
Foundation support plan		・ Foundation support method
Intake facility plan	Installation of two new pumps	・ Specifications of intake pump ・ Repairs to intake tower
Raw water main plan	One raw water main of 1200 mm size	・ Type and diameter of pipeline
	Equipment to prevent water hammering	・ Prevention method, structure
Water treatment facility plan	Basic items	・ Planned water treatment capacity (existing and expanded facilities)
	Improvements to existing facilities	・ Improvements to existing facilities ・ Installation of baffle walls at the inlet of the sedimentation basin
	Construction of new water treatment facilities	・ Water treatment method ・ No. of series of water treatment facilities
	Raw water receiving well/rapid mixing basin	・ Structure, rapid mixing method, raw water distribution method
	Flocculation basin	・ Agitation method
	Installation of new chemical settling basin	・ Construction of chemical settling basin
	Rapid filter	・ Filtration method, sand, back washing method, etc.
Drainage plan		・ Washing and draining methods
Chemical feeding plan	Chemical feeding facilities	・ Chemicals (type, feed rate) ・ Feeding equipment
Distribution reservoir plan	Distribution reservoir 5,000 m^3	・ Construction of distribution reservoir
Transmission/ distribution plan	Renewal of 3 distribution pumps Installation of 1 new distribution pump	・ Specifications of transmission/ distribution pump
Monitoring plan	Flow meter Water quality measurement and analysis	・ Flow rate measurement device (position, type) ・ Water level measurement device ・ Description of water quality analyzing device and sampling method
Electric/ instrumentation plan	Necessary instruments	・ Contents of necessary instrument
Plant connection plan	Plant connection pipes	・ Plant connection pipes (route, type of pipe)

(2) Plan for Capacity of Major Facilities

The planned daily maximum distribution volume of the Phum Prek WTP for the Project is 150,000 m^3/day. This volume is equivalent to the volume of water distributed from the WTP. Besides this volume of water, the WTP needs water for various kinds of work. The volume of water required for such work, for a distribution volume of 150,000 m^3/day was calculated as shown below.

Table 2 - 2-26 Total Capacity of Water Required for Work After Expansion

Item	Volume of water required
1) Water for dissolving chlorine	758 m^3/day
2) Coagulant dissolution	40 m^3/day
3) Water for feeding slaked lime	898 m^3/day
4) Water for miscellaneous work in the treatment plant	25 m^3/day
5) Water for washing flocculation basin and chemical settling basin	431 m^3/day
6) Water for washing rapid filter	5,793 m^3/day
7) Water for sampling	260 m^3/day
8) Water for other work (for repairing water meters, washing vehicles, vegetation, etc.)	164 m^3/day
Total	8,366 m^3/day = 8,400 m^3/day

The volume of water required for work is 8,366 m^3/day, so the total volume required for water treatment is 158,366 m^3/day. Under this Project, three intake pumps of 2,200 m^3/hour are scheduled to be in operation. This is equivalent to an intake volume of 158,400 m^3/day. This figure is almost the same as the total volume required for water treatment mentioned above. Accordingly, the volume of water required for work is taken as 8,400 m^3/day, so the total volume required for water treatment becomes 158,400 m^3/day. The volume of water required for work is about 5% of the total treatment volume. This figure is in the appropriate range.

If the total supply (distribution) capacity of the Phum Prek WTP after expansion is taken as 150,000 m^3/day, then the important planned water capacities will be as shown in Table 2-2-27. Using these capacities, and considering the actual capacities of various existing facilities, the required capacity of each facility after the expansion is estimated.

Table 2 - 2-27 Water Capacities of the Phum Prek WTP

Type of water capacity	Capacity	Reasons
Planned maximum intake and raw water volume	158,400 m^3/day	Maximum daily distribution volume x 1.056 (including water required for work in plant)
Planned daily maximum treatment volume	158,400 m^3/day	Maximum daily distribution volume x 1.056 (including water required for work in plant)
Distribution reservoir capacity	25,000 m^3	4 hours of maximum daily distribution volume
Maximum daily transmission/ distribution volume	150,000 m^3/day	
Maximum distribution volume per hour	8,750 m^3/hour	Planned maximum distribution volume per hour = Maximum daily distribution volume/24 hours x 1.4

Notes: Refer to 2-2-3 (7) and (8) for time coefficient and capacity of distribution reservoir

(3) Layout Plan of Planned Facilities

1) Plan for installation of new raw water main route

Underground structures as mentioned in Table 2-2-28 is buried along two routes of the existing raw water main. Therefore, new raw water mains cannot be installed in these routes.

Table 2 - 2-28 Underground Structures around Existing Raw Water Main Routes

Street 88	Street 90	Monivong Street
1) Raw water main 700 mm 2) Distribution pipeline 150 mm 3) Distribution pipeline 600 mm 4) Power lines x 2 sets 5) Telephone lines	1) Raw water main 700 mm 2) Drainage pipeline 600 mm 3) Drainage pipeline of WTP 800 mm 4) Distribution pipeline 200 mm 5) Distribution pipeline 200 mm 6) Power lines	1) Transmission pipeline 1100 mm (planned for installation in 2002) 2) Raw water main 700 mm 3) Raw water main 700 mm 4) Distribution pipeline 300mm (planned for installation in 2002) 5) Drainage pipeline 800 mm 6) Power line 7) Telephone lines

New raw water main routes as describe below are adopted such that the laying distance is minimum, no special work is required, construction cost is minimum and installation is easy.

Raw water main route: Overall length of about 1.55 km from the intake tower towards the south passing through the peripheral road of WAT PHNOM and the public park (medial strip), then passing by the side of the telephone station satellite to reach the raw water receiving well of the WTP.

This route avoids obstacles such as structures above the route and buried underground. The optimum layout of the new raw water main is as shown in Fig. GL-01 in 2-2-5.

The permission for laying the raw water main through public land such as roads and parks along the route has been obtained from the Phnom Penh city. The permission is attached as Appendix. A part of the raw water main route passes through land belonging to the telephone relay station. Permission for laying the raw water main on this land has also been obtained from the Ministry of Post and Telecommunication (MPTC). The permission is also attached as Appendix.

2) Layout plan of facilities in the WTP

The four main facilities to be newly constructed under this plan are mentioned below. A layout proposal for these four facilities is prepared.

- Facilities related to water treatment (water receiving well including rapid mixing chamber, water treatment facilities, and chemical feeding building)
- Distribution reservoirs

The planned facilities in the plant should be decided considering the following:

- Shape of the land on which construction is scheduled
- Integration with the layout of existing facilities
- Flow of water in the WTP
- Flow line of maintenance and operation

An approximate layout of water treatment facilities and water distribution facilities considering the points mentioned above is as given below.

- New water treatment facilities are arranged adjacent to and parallel to the existing water treatment facilities.
- New distribution reservoir is arranged adjacent to and parallel to the existing No. 2 distribution reservoir.

The layout of various facilities in the water treatment facilities is as given below.

- The raw water receiving well is arranged in the raw water inlet part.
- Space is reserved between the existing and planned water treatment facilities to park vehicles alongside so as to enable easy maintenance and operations of the existing facilities.
- The chemical feeding facilities are arranged near the inlet part of the planned water treatment facilities considering the following points:
  - Should be near the raw water receiving well, which is the most important chemical feeding point. This would enable easy monitoring of the chemical feeding status and the water treatment status.
  - Chemicals will be frequently transported into the chemical feeding building. Consequently, the building for chemicals should be located such that chemicals can be easily transported.

If the results of studies on the layout plans mentioned above and the shape of the facilities to be planned later are considered, then the layout plan of the facilities in the WTP will be as shown in Fig. GL-02 in 2-2-5.

3) Flow of water in the system

The flow of water in the system (from intake to distribution to the city) after the expansion of facilities based on the layout proposal is as shown in Fig. 2-2-9.

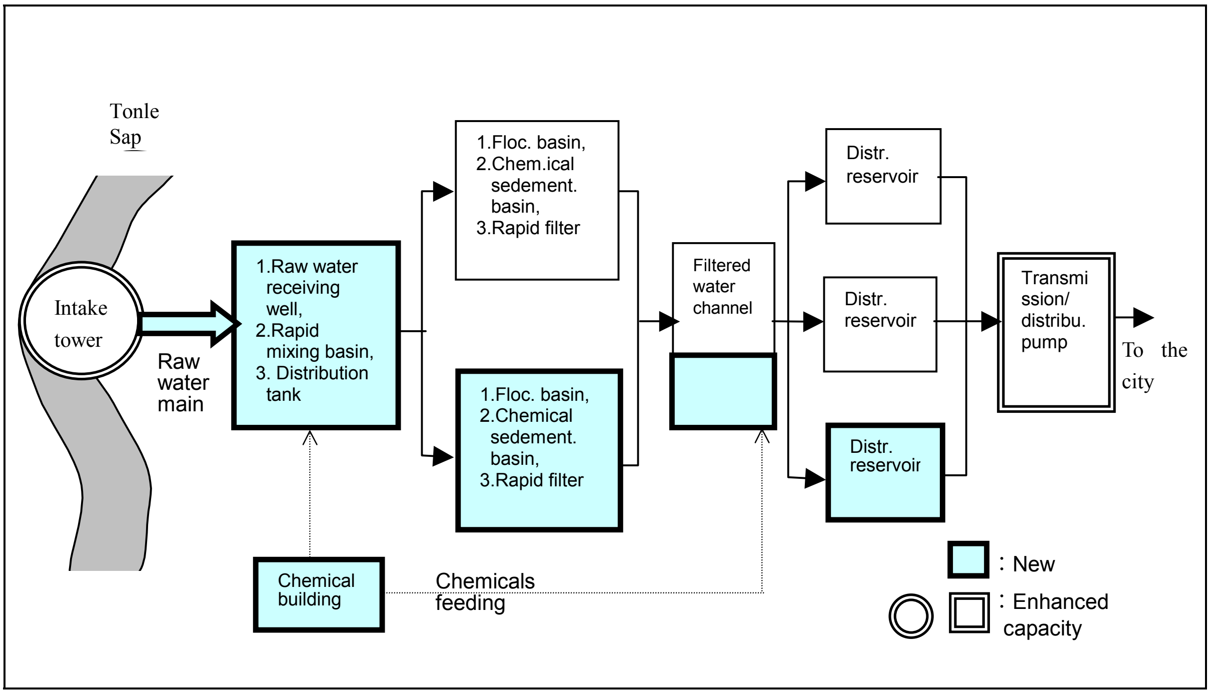


Fig. 2 - 2-9 Flow of Water in System after Expansion of Facilities

The raw water from the Tonle Sap is pumped at the intake point and flows through the raw water main to reach the raw water receiving well in the WTP. Next, the raw water is distributed from the water distribution tanks to the new and existing water treatment facilities. The treated water from the two facilities merges at the filtered water channel and flows into the distribution reservoir of the existing and new facilities where it is stored. Finally, the treated water merges in the pits of the transmission/distribution pumps and is transmitted/distributed to the city using the pumps.

(4) Water Level Plan of Facilities

The water level plan from intake to the distribution of water after the expansion of facilities is formulated. The water level plan after the expansion of facilities was formulated carefully considering the water level plan of the existing facilities. Table 2-2-29 gives an overview of the water level plan of the existing facilities.

Table 2 - 2-29 Water Levels at Important Points of the Existing and New Facilities

	Water level plan of existing facility	Planned water level after expansion of facility	
		Existing facility	Expanded facility
The Tonle Sap	+10.900 m (H) / +1.580 m (L)	Same as column on the left	
Raw water receiving well	+15.220 m	+16.400	
Rapid mixing basin	15.200 m	+15.200	
Flocculation basin	+15.170 m	+15.170	+15.160
Chemical settling basin	+15.165 m	＋15.154 m (front) / +15.160m (rear)	+15.154 (front)/ +15.152 (rear)
Filtered water channel	+15.020		+15.020
Filter	+15.140 m	+15.000 m	+ 15.000
Filtered water channel	**+13.200 m**	**+13.200 m** (reference water level)	
Distribution reservoir	+13.500 m (H) / +9.100 m (L)	Same as column on the left	Same as column on the left
Transmission/ distribution pump well	+13.500 m (H) / +8.710 m (L)	Same as column on the left	Same as column on the left

As indicated in the flow of water earlier, the treated water from the new and existing water treatment facilities merge at the filtered water channel. The water levels at all downstream locations should be the same as the existing water levels. Accordingly, upstream hydraulic plan should be formulated taking the water level at the existing filtered water channel + 13.20 m as the reference point, and then water level of the new WTP should be decided.

Hydraulic calculations are carried out to decide the water levels of the new WTP. Table 2-2-29 shows the important water levels of the new facilities including water levels of the existing facilities after the expansion (refer to Fig. WL-01 in 2-2-5).

(5) Foundation Support Plan for Structures

1) Foundation support method

Based on the soil tests investigations at the construction site, it is confirmed that there exists N-value of more than 20 and adequate soil strength to construct water containing concrete structures. Therefore, it is possible to support at least a concrete structure with pile foundation.

The soil survey results in the sites for proposed facilities during the basic design study have some inconsistency and are not enough to decide a proper foundation method. The optimum foundation method, therefore, should be studied and decided during the detailed design stage of this Project by conducting more detailed soil survey such as loading test.

2) Pile foundation

If pile foundation is adopted for this project, pre-stressed concrete pile (400 x 400 mm) made in Cambodia will be used. The following design capacity is used for the pile.

- Design allowable bearing axial force (Ra) = 85.0 ton per pile
- Design allowance load (Ra) = 40.0 ton per pile

(6) Intake Facility Plan

1) New pump plan

The plan for intake pump facilities with maximum daily intake capacity of 158,400 m^3/day is to be formulated.

Presently, three intake pumps of capacity 2,200 m^3/hour (one standby) have been installed in the intake pump tower. The tower has space for installing additional two pumps. As indicated in the basic plan (2-2-3-(3)) of this study, three new intake pumps (2,200 m^3/hour x 3 pumps) are to be installed, while two existing pumps are to be used and one existing pump should be removed from the pump stand.

Considering the planned water levels at the intake point of the raw water and at the receiving well in the WTP, vertical mixed flow pumps, similar to the existing pumps are considered suitable for use.

The pump head should be decided after comparing the pump installation costs, operation costs and construction costs of the raw water main. In other words, the smaller the pump head, the lower is the pump operation costs; however, in this case, the diameter of the raw water main has become larger and the construction cost of the raw water main is increases.

On the other hand, if the diameter is made smaller, the construction cost of the raw water main decreases, but a pump with higher head and higher operation costs is required. Under this plan, the minimum pump head required is 18 m, considering the planned intake water level, water level of the raw water receiving well and head losses near the pump.

Based on the reasons given below, specifications of new pumps are taken the same as that of existing pumps under this plan.

- All the electrical instruments of the existing intake pump facilities were repaired during the Project for Improvement of Water Supply Facilities in Phnom Penh (Phase I) by GOJ. Electrical instruments have been planned for the pump-motor output of 3000 V, 185 kW, 3 kV, 50 Hz. If new pumps with motor output differing from that of the existing pumps are installed, all electrical instruments have to be renovated. Additional costs of electrical instruments will be incurred, which is a major disadvantage.
- Under this plan, the existing pumps must also be used. By using the same specifications as the existing pumps for the new pumps, operation controls will become simpler.

Specifications of the new pump are given below (refer to Fig. IT-01 2-2-5).

Type: Vertical mixed flow pump
Flow rate: 2,200 m^3/hour
Total head: 21.0 m
Motor output: 185 kW, 3 kV, 50 Hz
Number of pumps: 3 (2 new and 1 renewal)

An example of operation of intake pump

New pump	2,200 m^3/hour per pump x 2 pumps = 2,200 m^3/hour =105,600 m^3/day
Existing pump	2,200 m^3/hour per pump x 1 pump = 2,200 m^3/hour = 52,800 m^3/day
Total	2,200 m^3/hour per pump x 3 pumps = 6,600 m^3/hour = 158,400 m^3/day

2) Repair plan for equipment in intake tower

A part of the equipment in the existing intake tower is to be repaired to obtain optimum condition of the facility.

a) Intake gate equipment

The intake tower has lower intake gates at two locations for intake of water at low level when the Tonle Sap water level is +1.50 m to +7.50 m, and upper intake gates at two locations for intake of water at high level when the river water level is +7.50 m and above. A water-regulating door is fitted at each intake gate. However, since the manual opening and closing mechanism of the regulating door is damaged, the door cannot be opened or closed. Through a year, intake of water has been only through the low water level gate. Thus, the low water level intake gate is being used for intake of raw water of high turbidity near the bottom from the Tonle Sap in the flood season. To reduce the operation load of the water treatment facilities, the intake should be raw water with low turbidity as far as possible. In this plan, the manual opening and closing mechanism of the upper and lower intake gates (1.0 x 1.0 at 4 locations) is to be repaired to ensure intake of good quality raw water by operating the lower and upper gates.

b) Overhead traveling crane

A six-ton electric overhead traveling crane has been installed in the existing intake pump room. The motor for the transverse-moving trolley of the crane has broken down and the trolley is incapable of transverse motion currently. Furthermore, the gear for the trolley winch has worn out. There is a distinct possibility that the gear may slip and drop the pump when it is being raised or lowered. In the present condition, the pump is likely to be damaged during its installation, removal or repairing. If it is damaged, its replacement is likely to be very expensive. Therefore, repairs to the trolley need to be incorporated in the plan.

c) Intake water level gauge

A portable immersion-type water level gauge is available in the intake pump well for measuring the water level of the river inside the tower. However, large errors in the water level measurement occur because the differential pressure measurement unit of the gauge becomes buried in the heaped sand during measurement. This is the main reason for the large deviation in the water level measurements in the pump well by PPWSA and the water level measurements of the Tonle Sap by the Ministry of Water Resource and

Meteorology (MWRM).

Ultrasonic water level gauges should be used that enable water level to be measured correctly regardless of sandy deposits. Such a measure will enable water levels to be correctly measured at all times. Means should be provided to enable the measured value to be recorded at all times in the control room of the WTP. This will ensure timely control of raw water inflow and number of intake pumps in operation.

(7) Raw Water Transmission Facility Plan

1) Raw water main plan

The raw water main should be capable of transmitting 158,400 m^3/day from the intake points even during low water levels of the Tonle Sap to the WT.P. As indicated in the basic plan (2-2-3(4)), one new raw water main is to be installed so that the water flow rate mentioned above is ensured. The existing raw water main can be used as backup during an emergency or during the washing of the new raw water main. As mentioned later, the diameter of the raw water main to be newly installed is taken as 1,200 mm.

2) Selection of type of pipe

Ductile cast iron pipe is adopted for pipes and fittings of the raw water main considering the large diameters of raw water mains, the records of use of pipelines in the Phnom Penh city, the policy for piping work of the PPWSA, the ease/difficulty of procurement, quality, economics and workability. Ductile pipe is also selected as the type of pipe for use in the transmission pipeline system (diameter 1100 to 1,400 mm) for the Phnom Penh city financed by the ADB.

- Construction period of each work section can be reduced since the pipe laying work is easy. This enables the work period to be reduced in areas with high traffic volume such as Monivong Street. The effect of the work on vehicular traffic is also small.
- Steel pipe welding work, lining work on the internal and external surface of welded parts of steel pipe and welding inspections by using X-rays are not required. Therefore, construction cost is reduced.
- Compared to steel pipe, the joining work is simple. Therefore, the work period is shorter.

・ Adequate strength can be ensured to resist external and internal pressures.
・ This type of pipe has good corrosion resistance and offers good workability.

3) Deciding the diameter of the pipe

The diameter of the raw water main is decided by hydraulic calculations. The flow coefficient (C) of ductile cast iron pipe with mortar lining on the internal surface is taken as 130, which is the value normally used in Japan for water pipeline.

$H = 10.666\, C^{-1.85}\, D^{-4.87}\, Q^{1.85} \cdot L$ (Williams & Hazen formula)
or $D = 1.6258\, C^{-0.38}\, Q^{0.38}\, H^{0.54}\, L^{-0.54}$
Where,

・ H: head loss (m) ：
・ C: Coefficient of flow velocity (dimensionless)：130 (coefficient of new cast iron pipe)
・ D: Diameter of pipe (m) ：1.2 m (or 1.1m)
・ Q： Flow rate (m^3/sec.) ： 1.834 m^3/sec (=158,400 m^3/day)
・ L: Length of route (m) ：1,550 m

The head loss in the intake/raw water main system excluding the raw water main when the planned intake volume is delivered are as given below. The total head loss is 1.94 m.
・ Head loss at the intake gate: 0.12 m
・ Head loss from the pump inlet to the newly installed pipe: 1.63 m
・ Head loss at the inlet part of the raw water receiving well: 0.19 m

The diameter of the raw water main is decided after comparing the head losses of pipes with diameter 1,100 mm and 1,200 mm. Based on the local losses mentioned above and the head loss of the straight sections of each raw water main, fittings and bends (12 % of head loss of the straight parts) given in the table below, the water level in the raw water receiving well was calculated. It was found that a water level greater than +1.64 m is required for the raw water receiving well from the hydraulic calculation mentioned earlier. Raw water main of dia 1100 mm cannot secure the required water level at the receiving well. Considering degradation of internal conditions of raw water main in the future due to the highly turbid raw water of the Tonle Sap, the diameter of the raw water main to be newly installed is taken as 1,200 mm.

Table 2 - 2-30 Selection of Diameter of Raw Water Main

	Head loss (m)			Water level of raw water receiving well
	Raw water main sections	local sections	Total loss	
Diameter 1,200 mm	2.88 m	1.94 m	4.82 m	+ 17.76 m
Diameter 1,100 mm	4.39 m	1.94 m	6.33m	+ 16.25 m

Note: Calculated based on the condition of the planned low water level of the Tonle Sap (+1.58 m).
The required water level greater than +16.4 m at the receiving well.

4) Accessory equipment

Accessory equipment such as regulating valves and air valves are incorporated in the plan referring to Japanese standards ("Guidelines on the Design of Water Supply Facilities," Japan Water Works Association).

a) Regulating valves

Regulating valves are to be located at important points and branching points of the raw water main. The main specifications are as given below.

① Type: Butterfly valve (diameter 1,200 mm)

② Material: Ductile cast iron

b) Blow-off valves

Blow-off valves are installed in inverted siphons or concave parts of the pipe. Sluice valve is selected as the type of valve.

c) Air valves

Air valves to be installed in the convex part of the pipe should be fitted.

d) Manhole

Manholes are to be installed for maintenance of the pipe at appropriate points of the pipe.

5) Plan for preventing water hammering

a) Equipment for preventing water hammering

Water hammering in a pump transmission system refers to the variation of pressure in a pipe that occurs because of the change in the flow of water during a power failure. The extent of water hammering varies depending on various conditions such as the magnitude of change of flow velocity in the pipe, length of the pipe, status of installation of pipe and the extent of inertia effects of the rotor (impeller).

If the water hammering pressure exceeds the allowable value, major accidents such as damage to machinery or pipe are likely to occur. Methods for preventing the water hammering pressure include the following:

① Fit a flywheel in the coupling connecting the pump and electric motor.
② Install a one-way surge tank in the pipeline.
③ Install the pressure tank (air vessel) in the pipeline just after the pump.

Fitting a flywheel costs less but it is impossible to install the existing pumps. This method cannot be adopted for this plan because the plan makes use of the existing pumps. In addition, the range of allowable positive or negative pressure of the flywheel is small.

If a surge-tank is installed, a very high tank (more than 20 m above ground) is required to be constructed. It is impossible to implement the plan when such a high tank is installed between the intake and the WTP.

For this project, the pressure tank (air vessel) method is adopted. This method is also the same as the method currently being used. The pressure tank should be installed above ground and between the raw water mains on opposite sides in the existing pressure tank room

b) Water hammering analysis and capacity calculations when air vessel is installed

If air vessels are installed, the capacity of the equipment should be decided based on the water hammering analysis. The calculation conditions are given below. Table 2-2-31 shows the analysis results.

Calculation conditions: 3 intake pumps in operation (flow rate 2,200 m^3/hour per pump x head 21 m)

: Raw water main (diameter 1,200 mm x length 1,600 m)

: Since the raw water main is newly installed, the head loss initially is assumed to be low at about 5%. (Discharge flow rate: 38.7 m^3/min. x head: 19.6 m (per pump))

: The initial air volume is assumed as 10 m^3.

Table 2 - 2-31 Water Hammering Analysis (When Air Vessel Installed)

(unit: m)

	Position of raw water main from intake tower (m)				
	0	400	800	1200	1600
Position of raw water main	12.8	9.0	9.0	9.0	9.0
Steady state water head	21.0	19.25	17.5	15.75	14.0
When water hammering occurs					
Maximum water head	6.9	13.9	14.2	14.1	14.0
Minimum water head	6.9	8.1	9.6	11.4	14.0

Note: Standard level: +1.46 m (Planned minimum water level in the intake tower)

As shown in the table above, changes in water level in the raw water main can be estimated. The negative pressure that occurs when no proposed air vessel exists, is eliminated; therefore, the risk of water column separation also disappears. The minimum head for the entire calculation period is 5.5 m.

The required capacity calculated using the Boyle-Charles Law after converting the head to absolute pressure is as given below.

P1=1.96+1.0 =2.96, V1=1.0

P2=0.55+1.0=1.55, V2=P1xV1/P2=19.1 m^3

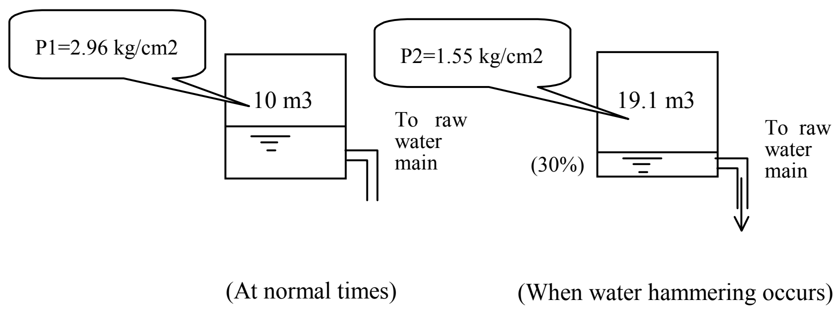


Fig. 2 - 2-10 Air Vessel Capacity Analysis

To prevent the leakage of air in the tank to the raw water main when water hammering occurs, 30% of the residual water in the tank should be available and an allowance of 30% capacity should be considered in case a higher water hammering action than designed occurs. Thus, the tank capacity should be about 36 m^3 (V2=19.1/0.7x1.3). Considering the space required for installation of the air vessel and a size that enables easy transportation, two vessels of 18 m^3 each should be installed in parallel.

(8) Improvement Plan for Existing Facilities

1) Overview

The treated water of the existing water treatment facilities do not satisfy the WHO standards for turbidity. The main reasons for this situation are the problems indicated in Table 2-2-32. These problems are to be resolved, and the quality of treated water in the existing facilities improved as far as possible so that it is close to the quality of treated water in the new facilities. Measures adopted this time are also shown in the same table.

Table 2 - 2-32 Problems of Existing Water Treatment Facilities and Measures Adopted in This Project

Problems	Description of problem	Measures
a) Inadequate retention time of the rapid mixing basin	A retention time greater than 1 minute (see Note 1) is necessary but the current retention time is only 0.5 minutes for the nominal treated water capacity of 105,600 m^3/day. Since the retention time is short, adequate mixing is not possible, and the floc formation in the flocculation basin in the next stage is unsatisfactory.	Plan formulated by adding the volume of the existing rapid mixing basin to the volume of the new mixing basin. Existing rapid mixing basin used as backup in an emergency.
b) Inadequate retention time of flocculation basin	A retention time greater than 20 minutes (see Note 1) is necessary but the current retention time is only 16 minutes for the nominal treated water capacity of 105,600 m^3/day. Since the retention time is short, floc formation in the existing water treatment facility is unsatisfactory and the sedimentation efficiency is poor.	No improvements to be made to the existing facilities. The new facilities will have additional capacity to compensate for the inadequacy of the existing facilities. That is, the capacity of the existing and new facilities will become 100,800 m^3/day and 57,600 m^3/day respectively.
c) Inadequate structure of chemical sedimentation basin	Since the shape of the inlet parts of sedimentation basins is not appropriate and no baffle wall is provided, the sedimentation efficiency is poor.	Baffle wall to be installed.
d) Inadequate design capacity of filter	Since the design capacity is 100,000 m^3/day, the filter is subjected to over load, and the efficiency of treatment of turbid water is poor.	Treatment load to be reduced by adopting the measure mentioned in b) above.

Notes: 1) The standard retention times of the rapid mixing basin and the flocculating basin are 1-2 minutes and 20-40 minutes respectively, according to the Guidelines on the Design of Water Supply Facilities," Japan Water Works Association.
2) Refer to 2-2-3 (6), for the description.

2) Raw water receiving well and rapid mixing basin

The required volume of the existing raw water receiving well and rapid mixing basin is added to the volume of the new raw water receiving well and mixing basin, as indicated in the basic plan (2-2-3(6)). Existing rapid mixing basin is to be used as backup in an emergency.

3) Flocculation basin and rapid filter

No improvements to be made to the existing facilities. The new facilities are to have additional capacity to compensate for the inadequacy of the existing facilities. That is, the capacity of the existing and new facilities will become 100,800 m^3/day and 57,600 m^3/day respectively. The changed treatment capacity of each existing flocculation basin will be as shown below.

- Number of flocculation basins ： 6
- Capacity of each flocculation basin ：233.8 m^3
- Retention time ： 20 minutes

  Notes: The treatment capacity of each basin after changes in water capacity are as indicated below.

  233.8 m^3 x 60 minutes/20 minutes x 24 hours = 16,833.6 (m^3/day) / 16,800 (m^3/day)

  (⇒ Total planned capacity = $\sum$Q=16,800 m^3/day x 6 basins = 100,800 m^3/day)

With the change in treatment capacity of the existing facilities, the filtration rate of the rapid filter becomes 156.9 m^3/day at normal operation and 171.2 m^3/day when one basin is being washed. Since the above figure is within the design rate of 180 m^3/day for the rapid filter, no problems are anticipated.

4) Improvements to the chemical sedimentation basin

The treatment efficiency of the existing sedimentation basin is not high. The turbidity of treated water in the existing sedimentation basin is generally less than 5 to 6 NTU (3 to 3.6 degrees) according to the report of a JICA third country expert in charge of water treatment (April 1999). During the basic design study, the turbidity of treated water of the existing sedimentation basin was in the range of 10-30 NTU (6-8 degrees).

The turbidity of treated water in sedimentation basins in Japan is generally regulated in the range of 0.5-0.8 degrees or below. According to standards of the Water Works Bureau of the Tokyo Metropolitan Government, if the turbidity is not regulated below 0.5 degrees, then there is no measure to prevent outflow of Cryptosporidium from the rapid filter.

Notes:

1 NTU x 0.6 = Turbidity in Japan (turbidity of kaolin)

Cryptosporidium refers to a water-based pathogen belonging to the Protozoa species.

As studied in 2-2-3 (6), the main reason for the low efficiency in reducing turbidity is the carryover of floc in the water collection trough due to turbulence, short-circuit flow and dense flow. The structure of the inlet part of the sedimentation basin is such that it causes stirring up of sludge. This is one of the main reasons for incomplete sedimentation.

The inlet part should be changed to the baffle wall type, which is generally used in water treatment facilities in Japan and which has a proven performance so that the water treatment ability of the existing chemical sedimentation basin can be improved.

The aperture ratio of the baffle wall is to be taken as 6% of the entire cross section and the baffle wall is to be installed immediately after the sludge pit. The baffle wall should be installed in such a way that it does not cause any damage to the existing structures.

(9) Planned Capacity for Water Treatment Facility

By implementing the measures necessary for the flocculation basin as shown in 2-2-4 (8), the design capacities of the existing and new facilities are planned as given below.

- Existing water treatment facilities: 100,800 m^3/day
- New water treatment facilities: 57,600 m^3/day
- Total water treatment capacity: 158,400 m^3/day

(10) Plan for New Water Treatment Facilities

1) Deciding the water treatment method

The treatment system in the existing Phum Prek WTP consists of flocculation basins, chemical sedimentation basins and rapid filters. This system is generally adopted in treatment plants and offers ease of maintenance and operation. Radical changes to the existing treatment system do not offer any advantages from the aspects of effective utilization of existing facilities and ease of operation. Accordingly, flocculation basins, chemical sedimentation basins and rapid filters used in the existing system, should be used for the new water treatment facilities as well.

2) Study of the number of systems in the new water treatment facilities

The number of systems in the existing water treatment facilities is 6. The facilities consist of 12 flocculation basins, 6 chemical sedimentation basins and 12 rapid filters. The number of systems for the new water treatment facilities is taken as 4 considering the points mentioned below. As a result, the new water treatment facilities would consist of 8 flocculation basins, 4 chemical sedimentation basins and 8 rapid filters (Refer to Fig. WT-02 in 2-2-5).

- The treatment capacity per system in the new water treatment facilities should be practically the same as the treatment capacity per system in the existing facilities. (The capacity per system in the existing facilities is 16,800 m^3/day.)
- If the number of systems is made to conform to that of the existing facilities, the number of systems after expansion of the facilities would ideally become 3. The length required in the facilities for installation of 3 systems cannot be accommodated in the available construction site.
- If 4 systems are to be installed, then they can be accommodated in the available construction site for the new water treatment facilities. In this case, the capacity per system will be 14,400 m^3/day, which is close to that of the existing facilities.

3) Raw water receiving well, rapid mixing basin and water distribution tank

The raw water receiving well for receiving the intake/raw water should be installed at the inlet part of the new water treatment facilities. As indicated in the basic plan (2-2-3(6)), the capacity of the new raw water receiving well and the rapid mixing basin requires to receive and mix the total volume of raw water in the water treatment facilities (158,400 m^3/day) after expansion including the existing capacity. Then only new raw water receiving well and the rapid mixing basin are used at normal operation. The existing rapid mixing basin can be used as backup during an emergency or during the washing.

To ensure ease of maintenance and operation, a combination of rapid discharge from pipe and weir fall should be used for rapid mixing. Mechanical means for rapid mixing should not be adopted. Rapid mixing is carried out in two stages for enough mixing. In the first stage, water should be rapidly discharged from the pipe while in the second stage it should be rapidly agitated using weir fall.

The water distribution tank used for distributing water to the existing and new facilities should be attached to the rapid mixing basin.

Non-mechanical float-type flow meters should be installed in the distribution weirs to facilitate maintenance and operation. The measurement of the raw water volume, currently not being implemented, facilitates the feeding of appropriate quantity of chemicals and thus helps to improve the treated water quality. Chemicals are added to the rapid mixing basin.

The flow of raw water in the raw water receiving well, rapid mixing basin and distribution tanks should be through the raw water receiving well, first stage rapid mixing chamber, baffle wall, distribution weir (second stage rapid mixing using free fall from the weir) and distribution tanks. (Refer to Fig.WT-01 in 2-2-5)

4) Flocculation basins in the new water treatment facilities

As mentioned earlier, four systems of flocculation basins are to be used for the new facility. The description and construction of the flocculation basins are given below.

- Number of basins: Total 8 basins with two basins per system
- Water treatment capacity: 57,600 m^3/hour (=0.667 m^3/second)
- Water treatment capacity per basin: 7,200 m^3/hour (=0.084 m^3/second)
- Retention time: 25 minutes
- Volume of each basin: 125 m^3

In the existing flocculation basins, slow agitation is being used for flocculation using a mechanical flocculator. Use of the same agitation system as used in the existing facilities is beneficial for the new facilities considering ease of maintenance and operation. Therefore, the mechanical flocculator should also be used in the new facility.

5) Chemical sedimentation basin

a) Description of structure

As mentioned earlier, four systems of chemical sedimentation basins are to be used. The description and construction of the chemical sedimentation basins are given below.

- Number of basins: Total 4 basins with one basin per system
- Water treatment capacity: 57,600 m^3/hour (=0.667 m^3/second)

- Water treatment capacity per basin: 14,400m m^3/hour (=0.167m m^3/second)
- Surface loading rate: 18 mm/minute (based on the Guidelines on the Design of Water Supply Facilities (Japan Water Works Association))

b) Inlet baffle walls, intermediate baffle walls and outlet baffle walls

Inlet baffle walls, intermediate baffle walls and outlet baffle walls are to be installed for preventing dense flows, short-cut flow, and turbulence in the sedimentation basin. Inlet baffle walls (aperture ratio about 6%) with fine holes uniformly distributed over the wall should be used in all the three types of baffle wall.

c) Settled water collection trough

Six water collection troughs of length 5 m each per basin should be installed to collect the required flow to the filter system.

d) Sludge discharging facility

Sludge discharge equipment with good ease of maintenance and operation that does not break down easily, similar to the existing equipment, should be used. Two sludge discharge pits should be installed at the most upstream ends of each sedimentation basin. Top valves of diameter 350 mm should be installed in the pit for discharging sludge.
e) Pressure pipeline for cleaning the facilities

Pressure water is required for washing (particularly for sludge removal) in water treatment facilities. Pipeline delivering pressure water and intake port should be installed around the new sedimentation basin by branching off the existing pressure pipeline in the existing filter gallery. The existing supply pump used for pressurized water should be used to make pressurized water for the new facilities.

6) Rapid filter

a) Rapid filtering method

Gravity-type rapid filters and backwashing method using both air and water are being used in the existing facilities. These methods are commonly used and they offer good treatment performance and ease of maintenance and operation. Gravity-type rapid filters and backwashing method using both air and water should also be used in the new facilities. There are advantages in using the existing backwashing system in the new facilities.

b) Filter inlet valves

Flap valves have been installed at the inlets of the existing filters to prevent the flow of filter backwashed water, extremely high turbid water into the sedimentation basin. Some of these valves are not functioning satisfactorily. Power-operated gate valves should be used at the inlet of the new rapid filters to ensure proper opening and closing of the valves.

c) Water collection equipment at the lower part of rapid filters

Strainers that enable backwashing using both air and water are being used as the water collection equipment at the lower part of the existing filters. Water collection means that enable backwashing using both air and water include strainers and porous concrete. Porous concrete should be used since it has excellent washing efficiency and repairs can be carried out locally if problems occur.

d) Backwashing equipment

Existing pumps and backwashing equipment using air (blowers) were replaced in 1995. Since the specifications and operations of these equipment are satisfactory, the same equipment should be used for the backwashing of the new filters also.

e) Air compressors

Butterfly valves with pneumatic actuator should be used for filtered water valve, in valves, backwashing valve, and air backwashing valve of the filters. The specifications and operations of the existing air compressor that supplies compressed air to the valves are satisfactory. The existing air compressor may be used also for the new filters.

f) Flow regulating equipment for filters

The same siphon-type flow meters as used in the existing facilities should be installed as flow regulating equipment for the new filters. The existing flow regulating equipment, made of steel, have corroded and rusted because of the chemicals used for water treatment. These equipment should be made of stainless steel in the new facilities so that rusting is prevented.

g) Head loss gauge

Differential pressure-type head loss gauges that can measure minute changes in air pressure, mounted on the head of the siphon-type flowmeter for monitoring the head loss in the filter, should be installed. The head loss in the filter should be displayed on the control panel of the filter.

7) Drainage plan

Presently, the washing water and the washed sludge in the existing WTP are being discharged into the Tonle Sap using the drainage pipeline (pipe diameter 800 mm). The same drainage facility should be used for discharging washing water and washed sludge from the new water treatment facilities. Only pipes connecting the existing drainage facility with the new water treatment facilities should be installed.

The treatment process of the expanded WTP generates 18 tons per day of sludge that contains silt from the raw water and chemicals fed in the treatment process. Presently, this sludge (12 tons per day) is discharged into the Tonle Sap without treatment.

There is no environmental effect of discharging this sludge to the river because of the following reasons.

- The silt discharged originally comes from the Tonle Sap and simply returns to the source.
- The chemicals used are harmless and stable and the quantity is extremely small compared to the large flow of the Tonle Sap and Tonle Mekong, even in the dry season.
- Presently, 12 tons per day of sludge is discharged into the river but no adverse impacts have been reported.

(11) Chemical Feeding Plan

1) New chemical building

As indicated in the basic plan (2-2-3(6)), a new chemical building should be constructed and the chemical feeding equipment of the existing and new water treatment facilities should be integrated. The similar structure and looks to the existing building in the WTP should be adopted for the structure and looks of the chemical building. As stated later, gravity-type feeding is adopted for the chemical feeding method for the expanded and existing facilities. Therefore, the feeding equipment should be installed at the second floor. The basic floor plan of the new chemical building should be as follows.

Table 2 - 2-33 Chemical Building Floor Plan

Story	Equipment and room
First	storage yard for chemicals and chlorine gas cylinders, and slaked lime saturators
Second	chemical feeding equipment, operation room for feeding equipment, a room for operators, a water quality analysis room and an office, and slaked lime saturators
Medium Second	office for water treatment engineers

2) Types of chemicals used and design feed amounts

Chemicals used in the Phum Prek WTP include: (a) aluminum sulfate as coagulant, (b) slaked lime as coagulant aid and pH regulator, and (c) chlorine gas for removal of organisms and bacteria.

Presently, chemicals imported from Vietnam are being used. These chemicals are imported periodically and there is no problem in their procurement. It is preferable that the same chemicals be used for the new facilities henceforth.

Other chemicals may also be used as coagulants. JICA third country experts have compared the costs of five types of coagulants (see Notes). The comparison showed that alum + anionic polymer has the lowest cost, and if this coagulant is used, a 5% savings approximately in the cost of chemicals can be attained compared to the use of alum only in the existing facilities. However, there are disadvantages such as the difficulty in maintenance, control and procurement of this chemical, and the need to use additional equipment. Since effective cost savings cannot be attained, emphasis should be laid on ease of maintenance and operation. Thus, aluminum sulfate, presently being used as coagulant in the existing facilities, should be used as the coagulant for both existing and new water treatment facilities.

Note: Report on Evaluation of Operation Performance at Phum Prek Water Treatment Plant, PPWSA. April 1999.)

New chemical feeding equipment capable of a water treatment capacity of 150,000 m^3/day should be installed. The design feed rate for each chemical should be as given in Table 2-2-34. The plan for new feeding equipment should take into consideration the design values. The study related to the setting of feed amount of chemicals is described below.

Table 2 - 2-34 Planned Chemical Feeding Rates

Chemical	Max. (ppm)		Average (ppm)		Min. (ppm)	
	Actual	Design	Actual	Design	Actual	Design
Aluminum sulfate	43.0	50.0	23.5	30.0	10.0	10.0
Slaked lime	—	10.0	—	7.0	—	5.0
Pre-chlorination	—	4.0	—	2.5	—	1.0
Post-chlorination in 1999	1.59	2.0	1.1	1.5	0.28	1.0
the first half of the year 2000	1.74		1.65		1.50	1.0

Actual: actual rates of feeding in the WTP

(Studies on planned chemical feeding rates)

① Aluminum sulfate

The design rates is set based on the actual rates measured every day in 1999 using jar tester.

② Slaked lime

A study is carried out on the need for pre-alkalization based on the results of jar test and raw water quality measurements. The alkalinity of raw water was generally in the range of 17 to 60 (mg/l) over the entire year. If coagulant is added to the raw water, its alkalinity (mg/l) reduces depending on the amount of coagulant added to the raw water. The alkalinity reduces by 0.45 (kg/l) when 1 mg/l of coagulant is added.

Assuming that 30 mg/l (design average feeding rate) of coagulant is added to raw water of alkalinity 30 mg/l, the alkalinity after coagulation becomes 16.5 mg/l. For coagulation to be effective, the alkalinity of raw water should generally be greater than 20 mg/l. This value cannot be satisfied.

Besides, when coagulant is added to raw water, the pH of the raw water decreases according to the feed rate. The pH of raw water is in the range of 6.79 to 7.82. Actual measurements in the existing WTP show that the pH value of the water in the existing sedimentation basin drops to as much as 6.3. To ensure ideal flocculation conditions, the pH value also needs to be regulated. In view of the reasons mentioned above, pre-alkalization is necessary.

The pH value has dropped to about 6.3 in the existing facilities. This value does not satisfy the water quality standards of WHO ($6.5 < pH < 8.5$). Consequently, post-alkalization is necessary for regulating pH during the period when the pH value drops below 6.5 (when the raw water is highly turbid and large amounts of coagulants are added). About 10 mg/l of slaked lime has to be added to increase the pH value from 6.3 to 6.5.

③ Pre-chlorination

Pre-chlorination equipment was installed just after the completion of the WTP but has never been used since then. There is, therefore, no previous feeding record for pre-chlorination.

Cyanophyceae (Blue-Green Algae), i.e. Anabaena, Microcystis, Phormidium and Oscillatoria, which cause water bloom, exist in the Tonle Sap Lake. These Cyanophyceae contain substances that are harmful to human health and which cause clogging of filters. In the dry season, these algae are discharged from the Lake to the Tonle Sap. The raw water including these algae is delivered to the WTP and water bloom is generated in the treatment facilities. Particularly in 1995 and 1997, massive water bloom occurred in the sedimentation basins and filters.

It is necessary to remove these Cyanophyceae for controlling algae. Copper sulfate and chlorine are used for elimination of algae. Chlorination is ordinarily used for water treatment process and should be adopted.

According to the design criteria for waterworks facilities in Japan, chlorine feeding rate for algae control should range from 0.5 to 3.0 mg/l. Ordinarily, massive water bloom seldom occurs in water treatment plant but it has occurred many times in the WTP. The actual feeding rate should be 3.0 mg/l maximum. The maximum chlorine rate is usually fed at 70 to 75% of the design capacity of the equipment. Therefore, the maximum design capacity of the equipment should be 4.0 mg/l.

④ Post-chlorination

The chlorine-feeding rate is determined based on the actual monthly average data in 1999 and in the first four months of 2000.

3) Chemical feeding method

Among the equipment in the water treatment plan, breakdowns occur most frequently in the chemical feeding unit. Its maintenance and operation are difficult. Mechanical feeding methods are presently being used and not all the equipment are operating satisfactorily. Considering the present situation in Cambodia, the ease of maintenance and operation of equipment, the difficulty in procuring spare parts and minimal breakdowns, gravity-type systems should be used in all chemical feeding equipment in the new facilities.

4) Tanks for dissolving solid coagulants and feeding equipment

Tanks for dissolving coagulant (4 tanks of capacity 8 m^3 each with agitator) and constant water level tanks (2 tanks of capacity 0.5 m^3 each with triangular weir flowmeter) should be installed on the second story of the new chemical feeding building. Chemicals should be fed by the gravity-feed method. These chemicals should be fed in the raw water receiving well.

5) Slaked lime feeding equipment

The existing slaked lime feeding equipment consists of pumps for feeding highly concentrated slaked lime solution (slurry). If this equipment is used, scales (deposits) are likely to be formed in the slurry transfer pipe causing the pipe to clog. Besides, impurities in slaked lime make maintenance and operation of the equipment more difficult. To eliminate the defects mentioned above, saturated solution of slaked lime should be prepared so that the clogging of the pipe due to slurry is prevented. Saturation tanks for preparing saturated solution of slaked lime should be installed. Saturation tanks are tall vertical tanks in which slaked lime is dissolved. Tap water is introduced from the bottom of the tank and saturated solution of slaked lime (0.15%) is extracted from the upper side of the tank. The saturated solution of slaked lime is produced when tap water passes through the slaked lime zone in the tank.

Saturation tanks should be made of reinforced concrete and should have a capacity of 48 m^3. An agitator should be installed in this tank. The tank for dissolving slaked lime fitted with agitator should be installed adjacent to the saturation tank.

Slaked lime used as coagulant aid should be added to the raw water receiving well. Slaked lime used as post-alkalization aid should be added to the filtered water. Considering that the filtered water and the slaked lime solution should be mixed adequately, the point at which the slaked lime should be fed should be taken as the point at which the filtered water channels of the new and existing facilities merge.

6) Chlorine feeding equipment

The existing chlorine feeding equipment consists of one feeder on which emergency repairs have been carried out. Space for storing four one-ton cylinders is available. Spare cylinders are stored outdoors. If chlorine leaks, neutralizing equipment will be required. But this neutralizing equipment has not been provided in the existing facilities. The existing chlorine feeding facility is in a highly dangerous condition.

Notes: As a security measure in Japan, a facility using one-ton chlorine cylinders must be provided with equipment for removal of chlorine that may leak.

For the present plan, a room for storing chlorine cylinders should be provided on the ground floor of the new chlorine feeding building and a chlorine feeding room should be provided on the second story. The room containing chlorine gas neutralizing equipment should be located adjacent to the room for storing chlorine cylinders on the ground floor.

The pressurized water injection method should be adopted as the chlorine feeding method since maintenance and operation are easy. The system of using two chlorine feeders for pre-chlorination (one feeder standby) and two chlorine feeders for post-chlorination (one feeder standby) should be adopted. Four pressurized water injection pumps for the chlorine feeders (two standby), each two for pre-and post chlorination, should be installed in the filtered water discharge valve room.

(12) Distribution Reservoir Plan

1) Capacity of distribution reservoir

Results of analysis of the distribution volume per hour show that the storage capacity of the distribution reservoir should be greater than the four-hour storage capacity of the maximum daily distribution volume. According to the basic plan (2-2-3(7)), the capacity of the new distribution reservoir is taken as 5,000 m^3. The capacity of the existing distribution reservoir is 20,000 m^3. Thus the total distribution capacity becomes 25,000 m^3. This figure is equivalent to the maximum daily distribution volume of four hours. If the capacity of the water distribution tower located in the center of the city is included, the distribution capacity becomes equivalent to the maximum daily distribution volume of 4.3 hours.

2) Shape and construction

The water level of the new distribution reservoir should be the same as that of the existing distribution reservoir. The effective depth of the distribution is 3.85 m. This condition and the shape of the planned construction site governs the shape and size of the distribution reservoir. The shape of the new reservoir should be half the rectangle of the existing No. 2 distribution reservoir (capacity 10,000 m^3).

The reservoir should be of reinforced concrete (RC) construction same as the existing distribution reservoir. This construction ensures the high waterproofing ability and durability required in the distribution reservoir. The construction is also simple, and the required resources can be procured locally.

(13) Transmission and Distribution Plan

1) Pump installation plan

According to the basic plan (2-2-3(8)), the pumps mentioned below need to be renewed and newly installed

- Renewal of three existing distribution pumps DP1-DP3 (nominal head 42 m; 2,100 m^3/hour)
- New installation of one distribution pump DP7 (nominal head 42 m; 1,050 m^3/hour)
  (Note: Refer to Fig. 2-2-11 for names and arrangement of pumps.)

2) Pump operation plan

The maximum distribution volume per hour from the new WTP is 8,750 m^3/hour. Pumps with transmission/distribution capacity greater than mentioned above are required to be installed. To distribute the maximum distribution volume per hour mentioned above, three distribution pumps of 2,100 m^3/hour capacity, two distribution pumps of 1,050 m^3/hour capacity and one transmission pump of 1,050 m^3/hour capacity are necessary, as shown in the pump operation example of Fig. 2-2-11.

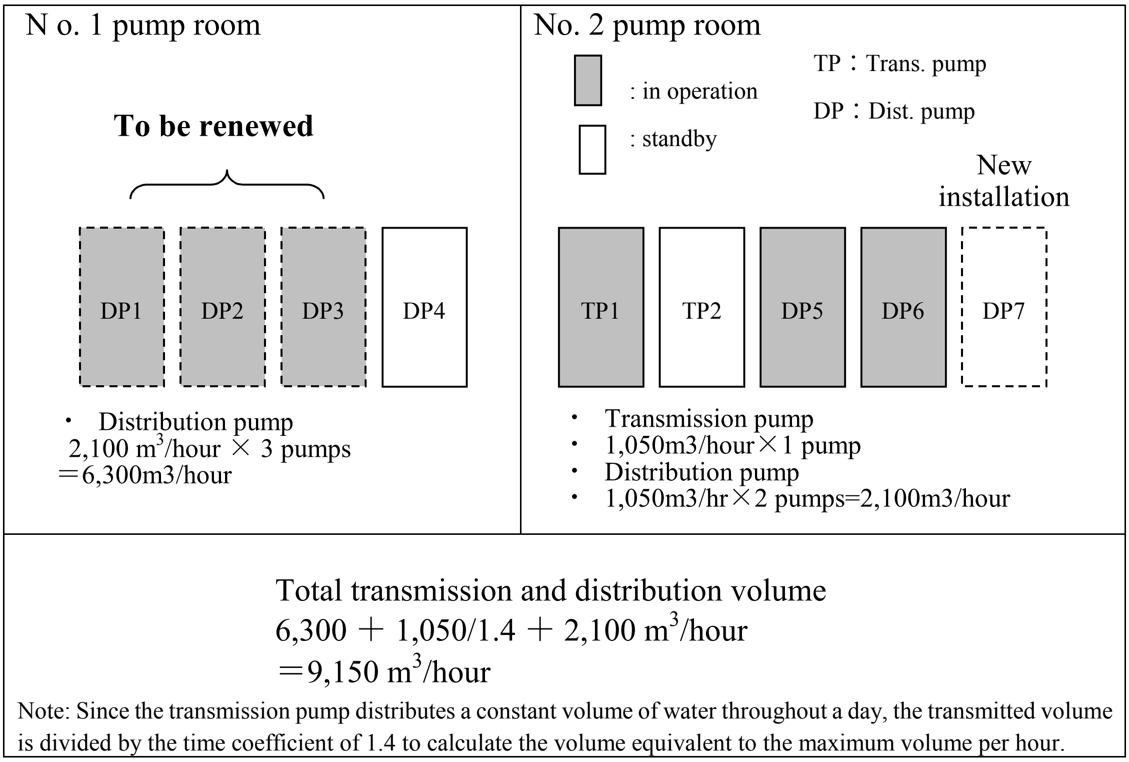


Fig. 2 - 2-11 Example of Pump Operation at Maximum Transmission/Distribution Per Hour

(14) Regulation of Inflow of Raw Water in the Water Treatment Plant

The water level of the Tonle Sap varies by about 10 meters in a year. The intake pump discharge rate varies depending on the variation in the water level. Thus, the raw water intake volume to the WTP varies. Presently, changes in the raw water flow are controlled by changing the number of pumps in operation, but accurate control of raw water flow is not possible. As a result, it is difficult to accurately estimate the amount of chemicals to be added to the water.

A spillway has been provided in the existing water treatment facilities. If the intake volume exceeds the capacity of water treatment, overflow occurs in the spillway, and the raw water is returned to the Tonle Sap. This is evidently a case of unnecessary wastage of energy.

The raw water entering the WTP should be controlled according to the distribution plan for water distributed from the plant in order to save energy and to ensure that appropriate amounts of chemicals are added to the raw water. The methods for controlling the raw water flow rate transmitted to the plant are as given below.

・ Control the number of pumps in operation
・ Control the pump rotation
・ Control the flow rate using flow regulating valves

The flow rate of water can be approximately controlled in stages by controlling the number of pumps in operation. However, this method does not ensure accurate flow control. The flow rate can be accurately controlled and energy can be used efficiently by controlling the pump rotation. Technically, this method offers the best improvements and saves energy. However, rotation control equipment are expensive and sophisticated technology is necessary to repair them in case they break down. Besides, spare parts are very expensive. Cambodia alone may find it difficult to provide the technology required for operating the rotation control equipment. In addition to the above, new electrical instruments must be installed for the equipment. Disadvantages especially from the standpoint of costs, maintenance and operation are too many, therefore, this method is not adopted in the plan. However, if the water supply project of the PPWSA progresses smoothly, spare part funds become available and technical skills are upgraded in the future, introduction of rotation control equipment will have to be studied.

Under the basic plan, manually operated flow control valves are to be installed for controlling the raw water flow. The float-type flowmeters installed in the raw water receiving well are to be used to monitor the flow, and the degree of opening of the flow control valves adjusted to control the raw water intake flow. The existing control method of changing of the number of pumps in operation is also used.

(15) Control and Monitoring Devices Plan

1) Flow monitoring device

a) Monitoring plan

The following items are currently monitored at control room of the WTP.

- Electric system : Conditions of power receiving (voltages, cycle etc.)

: Motor of pump (ampere etc.)

- Power : Work and stop of machines
- Water flow : 2 distribution flows
  : 1 transmission flow
  : 3 filtered water flow to reservoirs
- Water level : 3 distribution reservoirs
  : 1 distribution tower in the city

Presently, the items above are monitored that cover almost all items to be monitored in the water treatment plan.

Raw water flow at the inlet of the WTP is not currently monitored but should be monitored for the new WTP to improve the treated water quality and make operation easy. Considering conformity with the present status of monitoring, it should be monitored at the control room.

The water level of the Tonle Sap should be monitored at the WTP to control intake quantity properly, which varies with the water level. This monitoring can improve the treated water quality and make control of treated water volume easy.

The new float-type flowmeters installed in the raw water receiving well are to be used to monitor the inflow, and the degree of opening of the flow control valves adjusted to control the raw water intake flow.

b) Operation

The following three equipments are necessary to operate at a daily base. These are currently operated at the control room or automatically.

- Intake pumps (operated at the control room)
- Transmission/distribution pumps (operated at the control room)
- Back-washing (automatically operated or manually if necessary)

The new pumps and new transmission/distribution pumps should be controlled at the control room. The existing control method should be adopted for backwashing for new filters.

In this plan, the raw water valves are installed and raw water volume is controlled at the site.

2) Water flow monitoring device

In order to monitor water flow, existing and proposed device are indicated in Table 2-2-35 and Figure 2-2-12. Currently, flow measured by the existing device is monitored at the control room. Therefore, it shall be made possible for flow measured by the proposed device also to be monitored at the control room.

Table 2 - 2-35 Flow Monitoring Device

Flow	Existing Device	New Device	Reason for Adoption
Raw water flow	None	Weir type flow meter (1)	Maintenance is simple and expensive and sophisticated spare parts are not required.
Reservoir inflow	Electromagnetic flow meters (3)	Insertion type piezoelectric flow meter (1)	Accurate measurement is possible even when flow is minor.
In-plant work water flow	Electromagnetic flow meter (1)	-	-
Water transmission and distribution flow	Electromagnetic flow meter	-	-

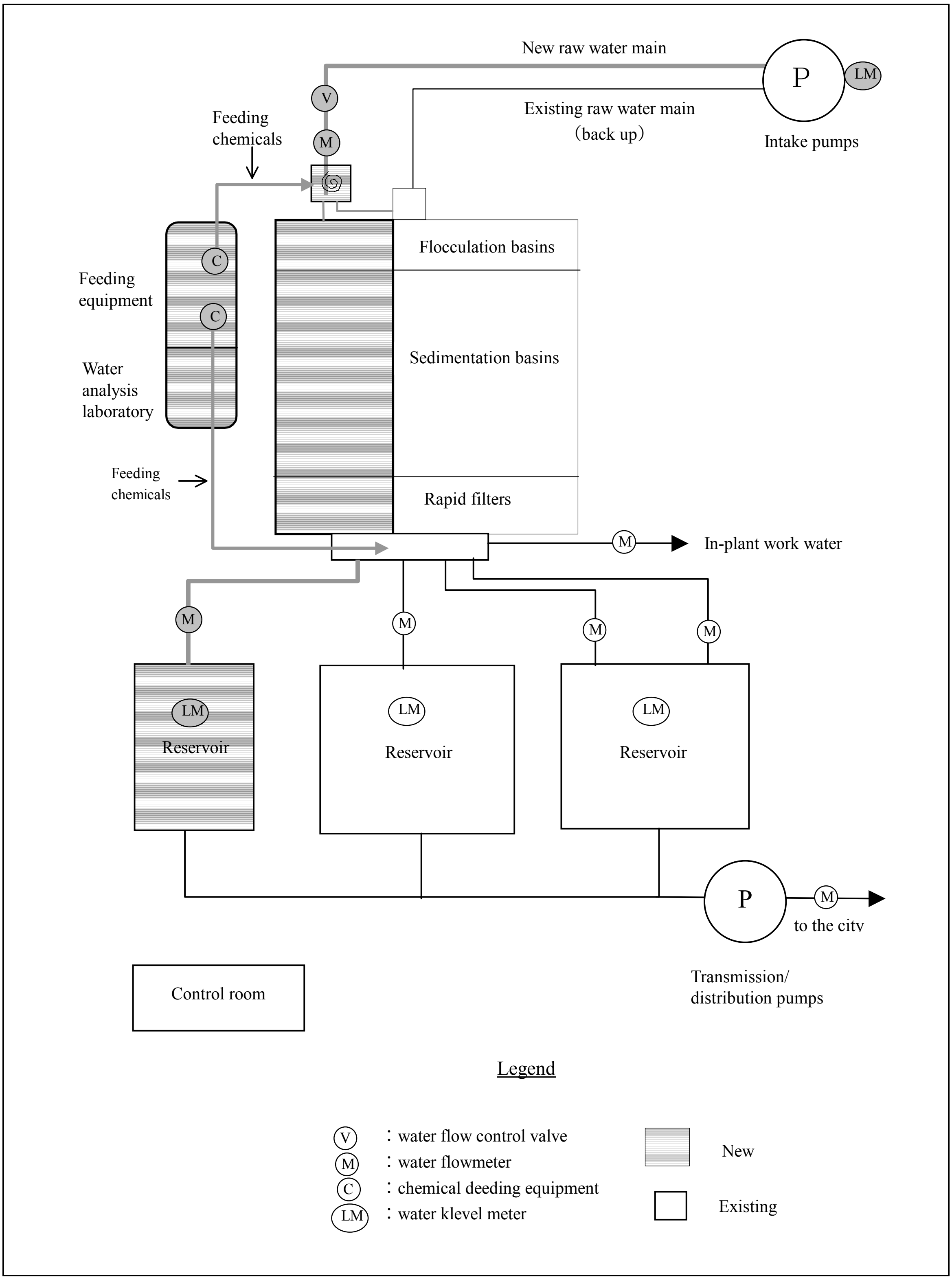


Fig. 2 - 2-12 Major Monitoring Devices in the Expanded Phum Prek WTP

3) River water level monitoring

In order to constantly carry out accurate measurement of fluctuations in water level in the intake tower, an ultrasonic water level gauge shall be installed.

4) Water quality monitoring

The purpose of carrying out water quality analysis can be divided into the following four items:

- To gauge the quality of raw water for appropriate feeding of chemicals
- To quickly detect changes in water quality at the source and to construct a treatment setup.
- To gauge water quality in the treatment process and to make sure that appropriate water treatment is taking place.
- To gauge water quality in the treatment process and to take appropriate measures in the event where water quality trouble occurs.

Precise test, analysis and control of water quality in the treatment process are essential in order to secure appropriate water quality of treated water. In particular, at coagulation-sedimentation and rapid filtration process, water quality control and monitoring capacity in each treatment process greatly depends on water quality analysis capacity.

a) Water quality analysis laboratory

In order to improve the quality of treated water, it is necessary to raise water quality analysis capacity. As indicated in the basic plan, it is planned to install a new water quality analysis room in the new chemical building and to install basic equipment necessary for testing and monitoring of water quality in the WTP. Moreover, sufficient space shall be secured to enable the installation of relatively sophisticated analysis equipment in order to upgrade the water quality analysis level.

It is necessary for the public water supply utility, which possesses multiple water treatment plants, to have a central water quality analysis laboratory capable of performing high level analysis at one location. The laboratory at the Phum Prek WTP plays a central role in water quality analysis not only for the PPWSA but for Cambodia as a whole. Therefore, it is necessary to convert this facility to be capable of performing high level analysis in the future.

As sated below, at least 85 m^2 area shall be secured for the water quality analysis room. As mentioned later, instruments to carry out physical and chemical tests and bacterial tests shall be supplied as a first step (See Table 2-2-37).

1) Physical and chemical test control area	30 - 40 m^2
2) Bacterial test control area	20 - 30 m^2
3) Biological test control area	15 m^2
4) Heavy metals and agricultural chemicals (gas chromatograph)	20 - 30 m^2
Total	85 - 115 m^2

b) Analysis instruments

It is planned to provide instruments to the water quality analysis room. Instruments to carry out physical and chemical tests and bacterial tests shall be supplied as in Table 2-2-37.

c) Water sampling sites and methods

It is necessary to transfer sampled water for water quality control from the sampling sites to the water quality monitoring room. Water sampling sites and sampling methods shall be as indicated below.

Table 2 - 2-36 Sampling Sites and Sampling Methods for Water Quality Analysis

Type of analysis water	Sampling site	Sampling method
Raw water	Upstream of raw water flow adjustment valve	Pump conveyance
Settled water	Existing and new settled water weir	Pump conveyance
Filter water	Existing and new filter water weir	Pump conveyance
Water distribution	Branch from distribution pipe	Distribution pump pressure conveyance

Table 2 - 2-37 Plan for Development of the Water Quality Analysis at Phum Prek WTP

Period		Present	First Stage (This project)	Second Stage (around 2006)	Third Stage (up to 2010)
Basic development concept		-	• Physical and chemical water quality test items • Bacterial tests	• Biological tests • Important heavy metals tests	• Heavy metals tests • Organic products, agricultural chemicals tests
Analysis method	Standard methods	pH value, turbidity, electric conductivity, SS, color, residual chlorine, alkalinity, hardness, carbon, potassium permanganate consumed, coliform group, faecal E-coli.	E-coli., general bacteria, evaporation residue, dissolved oxygen, total nitrogen, total phosphorous, phenol, surface active agent, etc.	BOD, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, arsenic, iron, fluorine, cyanide, etc.	iron, manganese, copper, zinc, nickel, silver, chrome, cadmium, selenium, mercury, organic substances, agricultural chemicals, etc.
	Simple methods	evaporation residue (TDS meter), dissolved oxygen (portable DO meter), sulfate ion, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, ion phosphate, ion chloride, fluorine, cyanide, aluminum, iron, manganese, potassium, chrome, copper, zinc, silica	lead, cadmium	mercury	
Necessary instruments, etc.			spectrophotometer, analytical scales, autoclave, water bath	thermostatic chamber, distiller, ion chromatograph, muffle oven	atomic absorption, photometer, metal lamps, reduction vaporizer, hydride generator, gas chromatograph, purge trap device, condenser (evaporator), solid column
Expendable items		HACH DR2000 reagents, bacterial inspection reagents, other reagents	guaranteed reagents, standard substances, bacterial inspection reagents, etc.	guaranteed reagents, standard substances, bacterial inspection reagents, etc.	guaranteed reagents, standard substances, high purity gas, etc.

(16) In-plant Connection Plan

1) Connecting pipe between distribution tank and flocculation basin

Concerning the pipe which connects the distribution tank to the existing flocculation basin, pipe of dia. 1,350 mm for the existing basin and dia. 1,000 mm for the new basin shall be required and it shall be ductile iron pipe with inner mortar lining.

2) Connecting pipe between collection channel of filtered water and new distribution reservoir

This pipe shall be connected to a part of the pipe linking the 700 mm diameter outflow pipe installed in the existing filtrate outflow valve room to the new distribution reservoir. The pipe shall be made from ductile iron with inner mortar lining. An insertion type piezoelectric flow meter shall be installed midway along the pipe, and measured flow shall be electrically transmitted to and monitored from the control room.

3) Connecting pipe between the new and existing distribution reservoir bypass pipes

A new pipe shall be installed to connect the bypass pipe between the new distribution reservoir and the inlet pipe of the distribution reservoir. The pipe shall have a diameter of 700 mm and shall be made of ductile iron with inner mortar lining.

4) Distribution main

Three distribution pipes of 600 mm, 700 mm and 800 mm in diameter currently distribute water to the city. Distributed water flow from the WTP will increase in line with expansion of the plant.

The 700 mm and 800 mm pipes will be connected to the ADB project water transmission pipe before this project is completed. Concerning the ADB connection point of the 800 mm pipe, it is planned for pipe with a diameter of 1,000 mm to be connected, while in this project, it is planned to connect to the 1,350 mm distribution main installed in the treatment plant valve room. The pipe shall have diameter of 1,000 mm and shall be made of ductile iron with inner mortar lining.

5) Connecting pipe between the new water treatment facilities and existing drainage facilities

In order to drain the backwashing water and the settled sludge generated from the new treatment facilities, a pipe connecting the new facilities to the existing drainage shall be installed.

(17) Electric and Instrumentation Plan

The total capacity of the existing power transformer equipment rehabilitated under the Project for the Improvement of Water Supply Facilities (Phase I) was 3,000 KVA. Since capacity is still not more than 3,000 KVA even after adding the necessary capacity following the expansion, there is no need to increase the capacity of power transformer equipment in the project. New installation and improvement works for the electric equipment in the project are as follows.

Table 2 - 2-38 Electric Equipment Installation and Improvement Works

Electric Equipment	Main Sites
Pump start panel	Intake pump electricity room
Auxiliary relay panel accompanying the pump start panel	Intake pump electricity room
Additional installation of control cable, etc.	Along raw water main (intake pump rooms - WTP)
Renovation of existing local panel circuitry, etc.	Side of renewed distribution pump
Renovation of central monitoring panel (addition of expanded facilities monitoring panel)	Control room

Addition of the following instrumentation equipment is required in the control room and filter operating gallery.

Table 2 - 2-39 Addition of Instrumentation Equipment

Instrumentation Equipment	Installation Site
River intake water level indicator	Control room
Raw water flow indicator and integrator	Control room
Filtration loss head meter	Filter operating gallery
In-reservoir flow indicator and recorder	Control room
Distribution reservoir water level indicator (new distribution reservoir)	Control room

(18) Summary of Planned Works of the Project

The planned works and equipment and instruments for water quality analysis of the project are summarized in Table 2-2-40 and Table 2-2-41.

Table 2 - 2-40 Project Summary

No.		Work Items
(1) New Construction and Rehabilitation		
1.	Intake pump facilities	
	1.1	Installation of pumps (3 sets, 2200 m^3/hour)
	1.2	Rehabilitation of the intake equipment (intake gates, crane, and water level gage)
	1.3	Rehabilitation of the existing access bridge
	1.4	Repainting of the existing intake tower and the access bridge
2.	Raw water main	
	2.1	Installation of a raw water main (φ1,200mm)
	2.2	Installation of an air vessel facility
	2.3	Installation of incidental equipment
3.	New water treatment facilities (50,000 m^3/day)	
	3.1	Construction of a receiving, rapid mixing, and water distribution basin
	3.2	Construction of flocculation basin
	3.3	Construction of sedimentation basin
	3.4	Construction of rapid sand filter
4.	Chemical dosing facilities (150,000 m^3/day)	
	4.1	Installation of feeding equipment for alum sulfate
	4.2	Installation of feeding equipment for slaked lime
	4.3	Installation of feeding equipment for chlorine
	4.4	Construction of a chemical building
	4.5	Supply of equipment and instruments for water quality analysis
5.	Construction of a reservoir (5,000 m^3)	
6.	Distribution pump	
	6.1	Installation of a new distribution facility (1050 m^3/hour)
	6.2	Renewal of the existing distribution pumps (3 sets, 2100 m^3/hour)
7.	Installation of electric and metering instruments	
8.	Installation of connection pipelines including a distribution main	
9.	Improvement of the existing sedimentation basin (Installation of baffle wall in the inlet of the basin)	

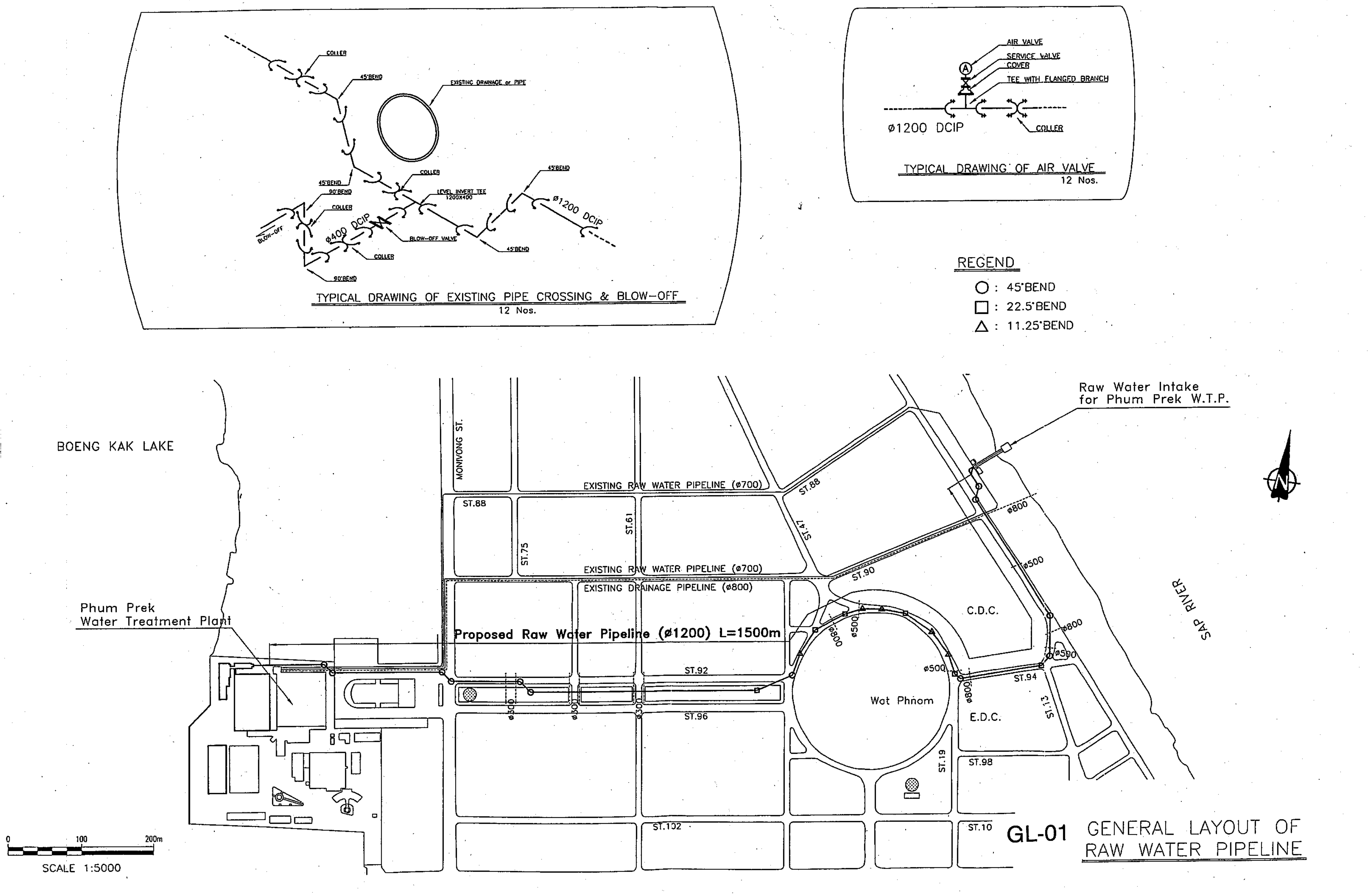
Table 2 - 2-41 Equipment and Instruments for Water Quality Analysis

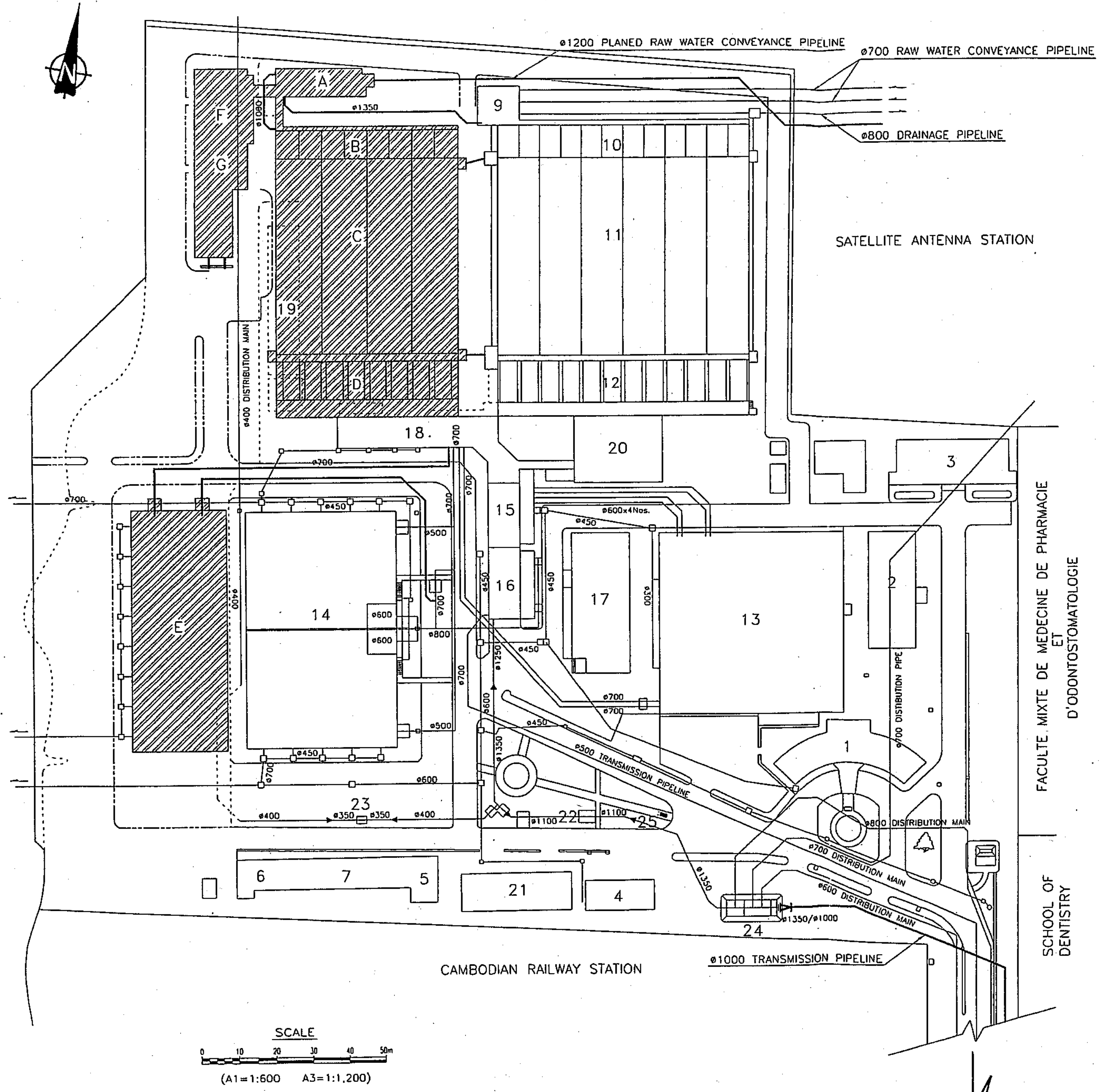
Equipment and Instruments	Quantity
1. Fume hood with blower, ceramitite	1 No.
2. Center table with sink	1 No.
3. Center table with reagent shelf (with glass door)	2 Nos.
4. Jar tester, 6 shafts	1 No.
5. Digital thermometer	1 No.
6. Personal pH meter (with electrode, pH standard solution)	1 No.
7. Digital temperature, humidity and dew point meter	1 No.
8. Electric conductivity meter	1 No.
9. Direct reading type turbidity meter	1 No.
10. Drying oven	1 No.
11. Autoclave	1 No.
12. Rack with metal fittings	1 No.
13. Magnetic mixer	1 No.
14. Water distillation apparatus	1 No.
15. Glass instruments	Necessary quantity
16. Reagent	Necessary quantity

2 - 2 - 5 Basic Design Drawing

Basic design drawings consist of the followings:

GL-01 General Layout of Raw Water Main
GL-02 General Layout of Phum Prek Water Treatment Plant
WR-01 Water Level of Facilities
IT-01 Intake Tower
IT-02 General Plan of Intake Facilities and Detail of Piping of Raw Water Pipe
WT-01 Receiving Well, Rapid Mixing and Distribution Tank
WT-02 Flocculation basin, Sedimentation Basin, Filter and Gallery
CH-01 Chemical Storage and Feeding Building
WR-01 5000 m^3 Reservoir
DP-01 Pump Room (No.1)
DP-02 Pump Room (No.2)


TYPICAL DRAWING OF EXISTING PIPE CROSSING & BLOW-OFF
12 Nos.
COLLER
45°BEND
EXISTING DRAINAGE or PIPE
90°BEND
LEVEL INVERT TEE 1200X400
BLOW-OFF
BLOW-OFF VALVE
ø400 DCIP
ø1200 DCIP
TYPICAL DRAWING OF AIR VALVE
12 Nos.
AIR VALVE
SERVICE VALVE
COVER
TEE WITH FLANGED BRANCH
ø1200 DCIP
COLLER
REGEND
○ : 45°BEND
□ : 22.5°BEND
△ : 11.25°BEND
Raw Water Intake
for Phum Prek W.T.P.
BOENG KAK LAKE
SAP RIVER
Phum Prek
Water Treatment Plant
Proposed Raw Water Pipeline (ø1200) L=1500m
EXISTING RAW WATER PIPELINE (ø700)
EXISTING RAW WATER PIPELINE (ø700)
EXISTING DRAINAGE PIPELINE (ø800)
MONIVONG ST.
ST.88
ST.75
ST.61
ST.47
ST.90
ST.92
ST.96
ST.94
ST.13
ST.19
ST.98
ST.132
ST.10
C.D.C.
E.D.C.
Wat Phnom
ø800
ø500
ø300
SCALE 1:5000
0
100
200m
GL-01
GENERAL LAYOUT OF
RAW WATER PIPELINE

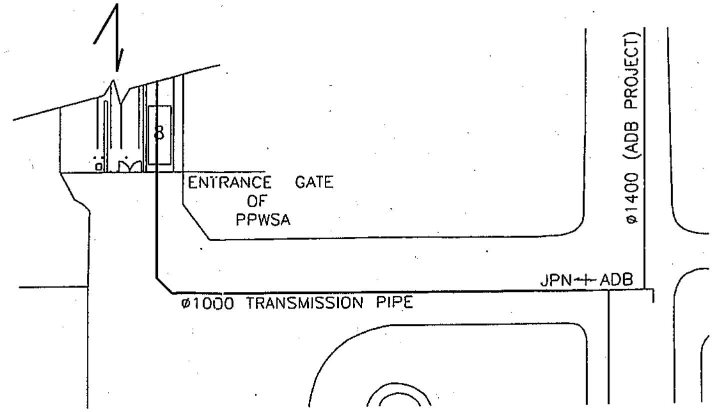


PLANED STRUCTURES

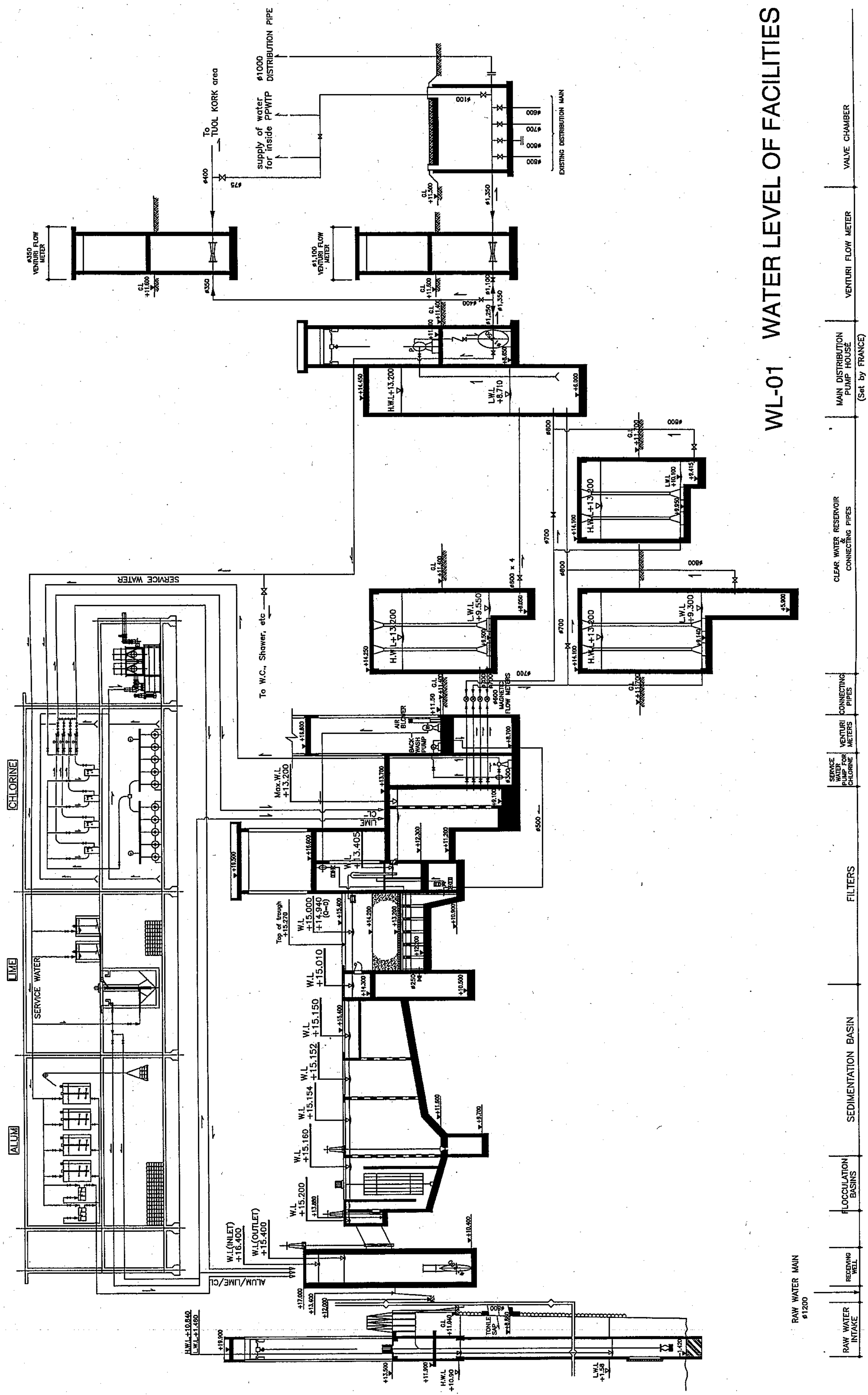
No.	NAME
A	RECEIVING & FLUSH MIXING BASIN (150,000m3/day)
B	FLOCCULATION BASIN
C	SEDIMENTATION BASIN (50,000m3/day)
D	FILTERS (50,000m3/day)
E	No.3 CLEAR WATER RESERVOIR (5,000m3cap..)
F	CHEMICAL FEEDING ROOM (150,000m3/day)
G	CHEMICAL STOREHOUSE

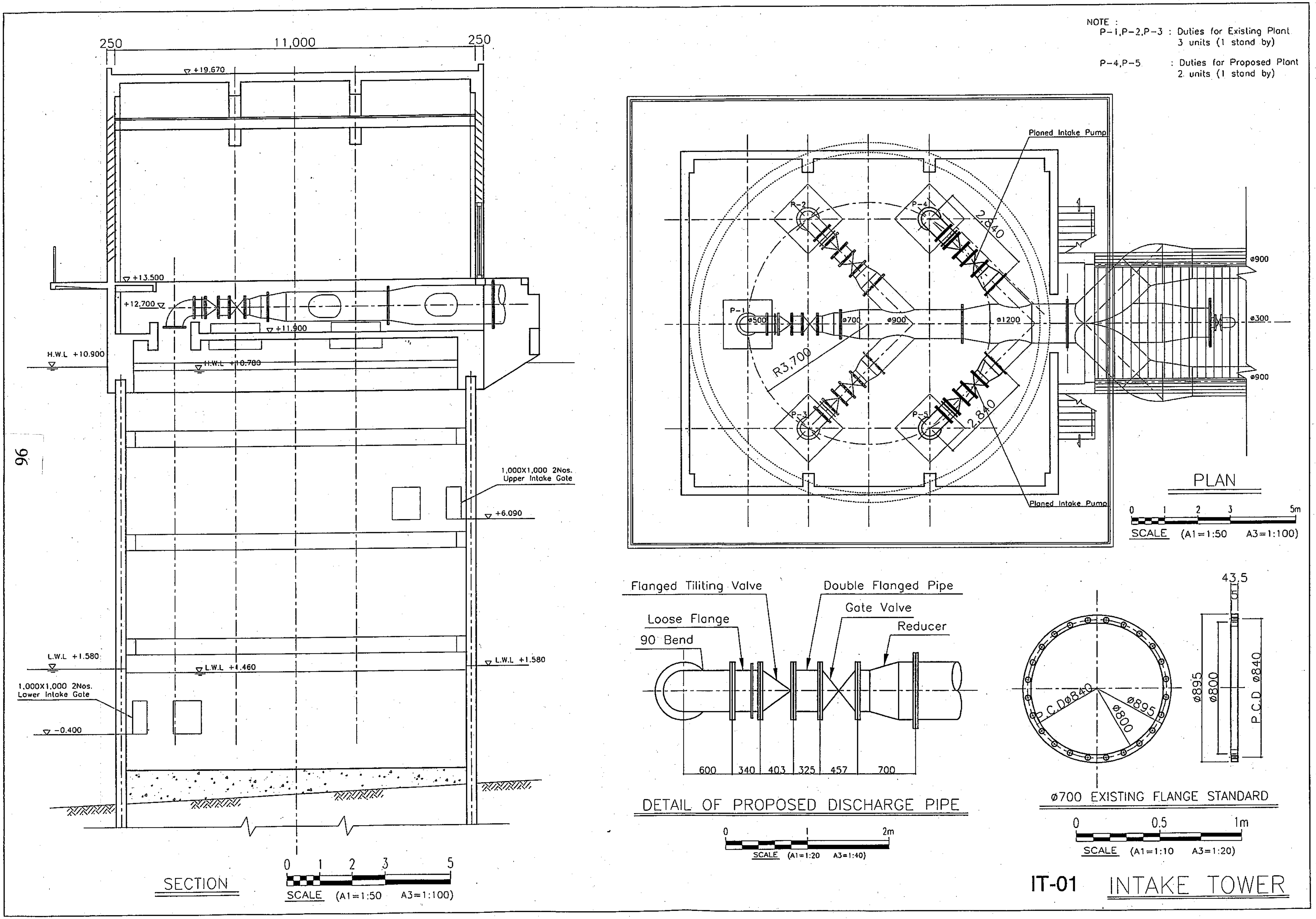
EXISTING STRUCTURES

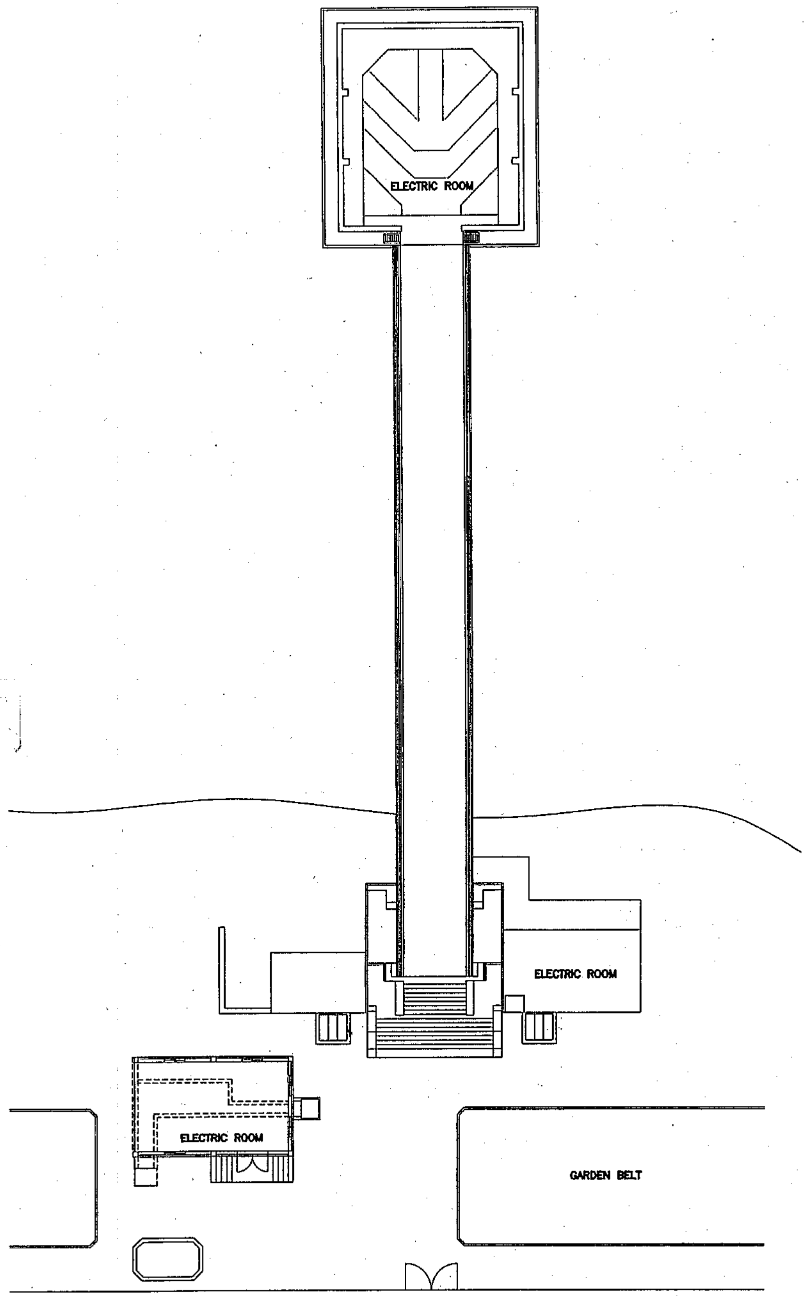
No.	NAME
1	HEADQUARTERS OF PPWSA
2	ADMINISTRATIVE BUILDING
3	DEPARTMENT OF TECHNICAL & PROJECT
4	DEPARTMENT OF PRODUCTION & DISTRIBUTION
5	WATER METER REPAIR SHOP
6	WORK SHOP
7	OFFICE OF THE PROJECT
8	GUARD HOUSE
9	RECEIVING & FLUSH MIXING BASIN (100,000m3/day)
10	FLOCCULATION BASIN
11	SEDIMENTATION BASIN (100,000m3/day)
12	FILTERS (100,000m3/day)
13	No.1 CLEAR WATER RESERVOIR (10,000m3cap., constructed in 1959)
14	No.2 CLEAR WATER RESERVOIR (10,000m3cap., constructed in 1995)
15	PUMPING STATION (constructed in 1966)
16	PUMPING STATION (constructed in 1995)
17	ELECTRICAL ROOM
18	CHEMICAL FEEDING ROOM (100,000m3/day)
19	CHEMICAL STOREHOUSE
20	No.1 PIPING MATERIALS STOREHOUSE
21	No.2 PIPING MATERIALS STOREHOUSE
22	DISTRIBUTION FLOW METER (ø1,000mm)
23	DISTRIBUTION FLOW METER (ø400mm)
24	ISOLATING VALVES CHAMBER
25	MONUMENT OF PHASE I JAPAN ODA



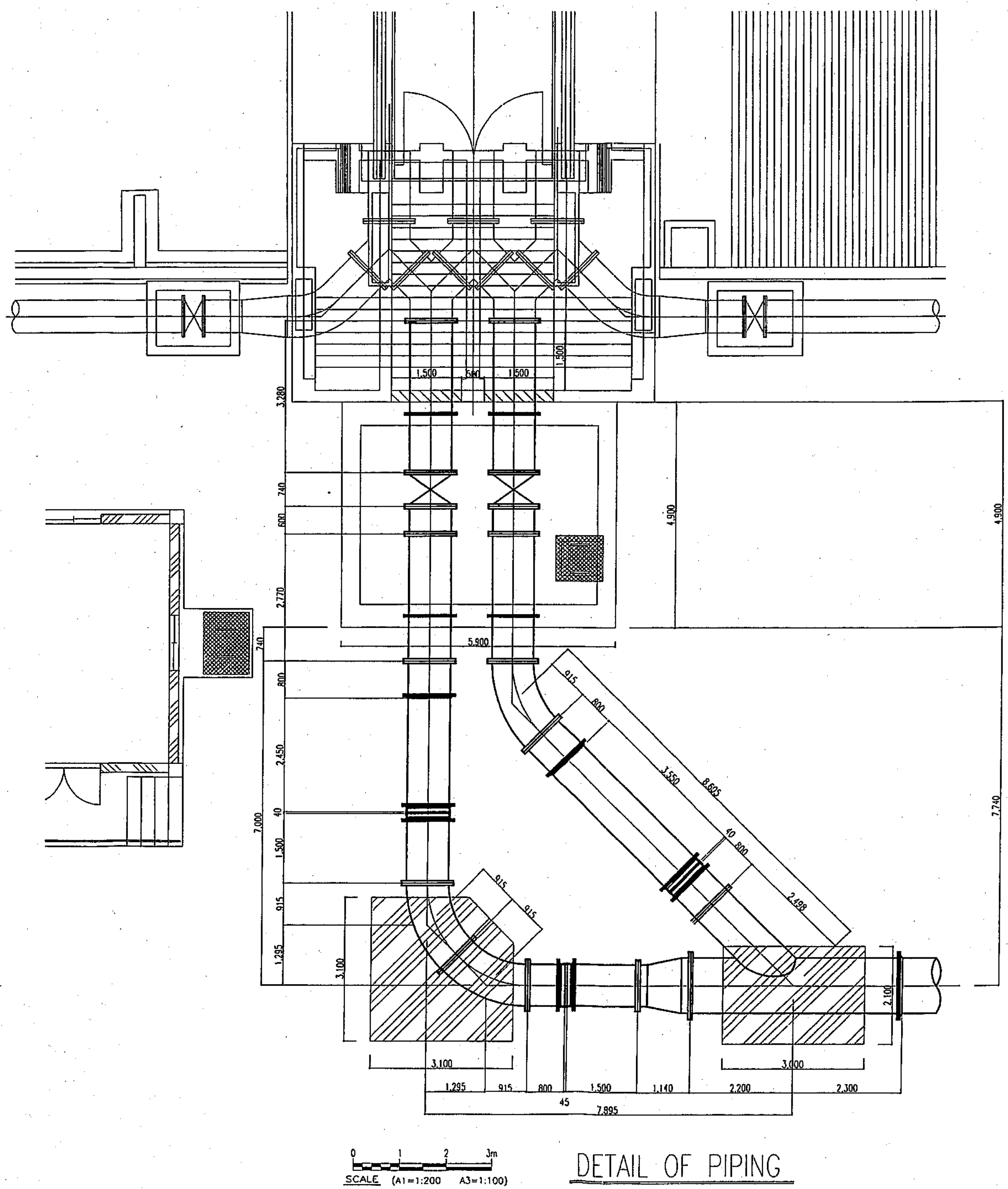
GL-02 GENERAL LAYOUT OF PHUM PREK TREATMENT PLANT


WL-01 WATER LEVEL OF FACILITIES
RAW WATER INTAKE
RAW WATER MAIN ø1200
RECEIVING WELL
FLOCCULATION BASINS
SEDIMENTATION BASIN
FILTERS
SERVICE WATER PUMP FOR CHLORINE
VENTURI METERS
CONNECTING PIPES
CLEAR WATER RESERVOIR & CONNECTING PIPES
MAIN DISTRIBUTION PUMP HOUSE (Set by FRANCE)
VENTURI FLOW METER
VALVE CHAMBER
ALUM
LIME
CHLORINE
SERVICE WATER
ALUM/LIME/CL
To W.C., Shower, etc
To TUOL KORK area
supply of water for inside PPWTP
ø1000 DISTRIBUTION PIPE
EXISTING DISTRIBUTION MAIN
W.L(INLET) +16.400
W.L(OUTLET) +15.400
W.L +15.200
W.L +15.160
W.L +15.154
W.L +15.152
W.L +15.150
W.L +15.010
W.L +15.000
Top of trough +15.270
Max.W.L +13.200
H.W.L+13.200
L.W.L +9.550
L.W.L +9.300
L.W.L +8.710
H.W.L +10.840
L.W.L +1.480
TONLE SAP
ø350 VENTURI FLOW METER
ø1,100 VENTURI FLOW METER
AIR BLOWER
BACK-WASH PUMP
MAGNETIC FLOW METERS

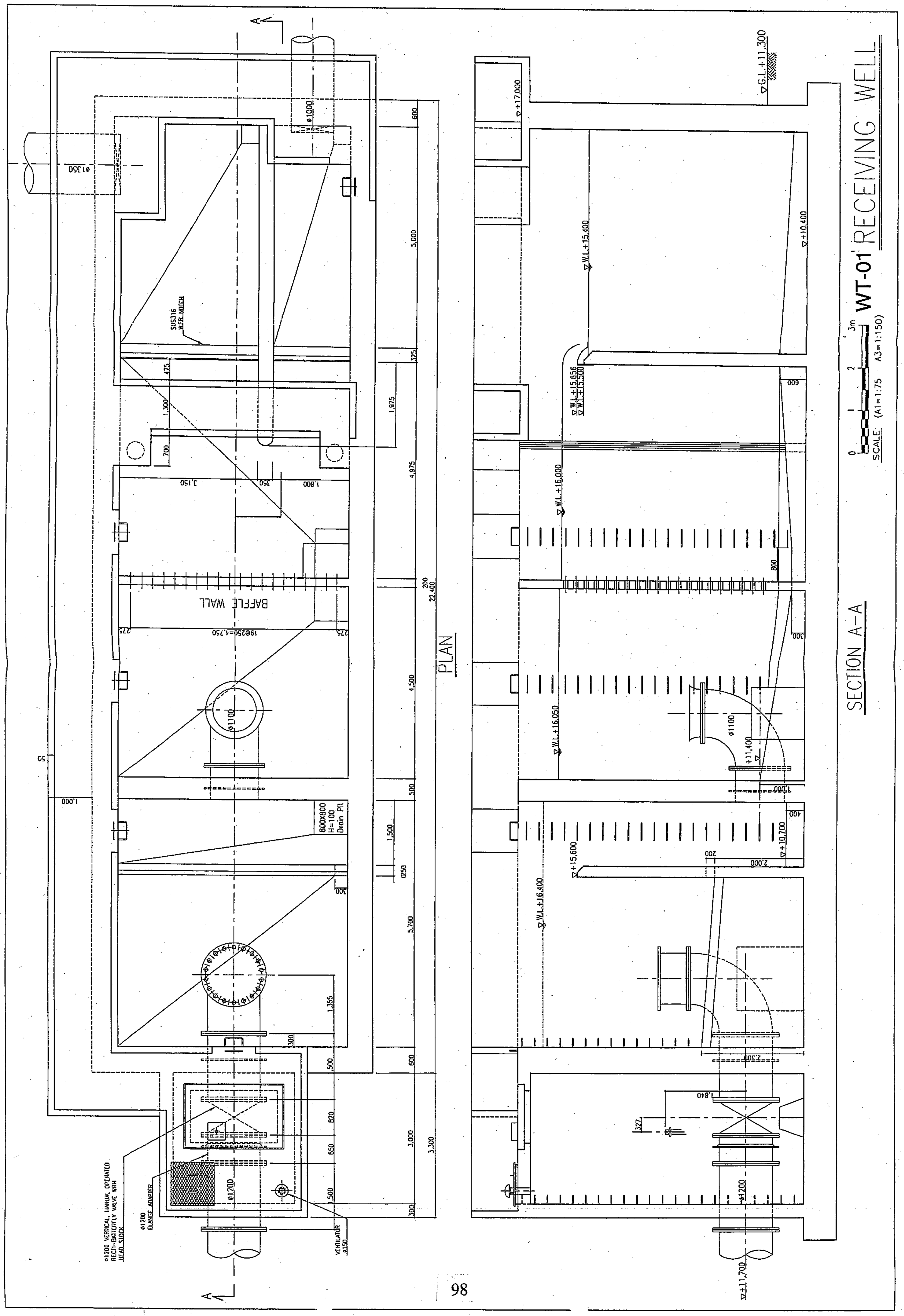

NOTE :
P-1,P-2,P-3 : Duties for Existing Plant 3 units (1 stand by)
P-4,P-5 : Duties for Proposed Plant 2 units (1 stand by)
250
11,000
250
+19.670
+13.500
+12.700
+11.900
H.W.L +10.900
H.W.L +10.780
1,000X1,000 2Nos. Upper Intake Gate
+6.090
L.W.L +1.580
L.W.L +1.460
L.W.L +1.580
1,000X1,000 2Nos. Lower Intake Gate
-0.400
SECTION
0 1 2 3 5
SCALE (A1=1:50 A3=1:100)
Planed Intake Pump
Planed Intake Pump
P-1
P-2
P-3
P-4
P-5
ø500
ø700
ø900
ø1200
ø900
ø300
ø900
R3,700
2,840
2,840
PLAN
0 1 2 3 5m
SCALE (A1=1:50 A3=1:100)
Flanged Tiliting Valve
Double Flanged Pipe
Loose Flange
Gate Valve
90 Bend
Reducer
600
340
403
325
457
700
DETAIL OF PROPOSED DISCHARGE PIPE
0 1 2m
SCALE (A1=1:20 A3=1:40)
43.5
5
P.C.Dø840
ø895
ø800
ø895
ø800
P.C.D ø840
ø700 EXISTING FLANGE STANDARD
0 0.5 1m
SCALE (A1=1:10 A3=1:20)
IT-01
INTAKE TOWER

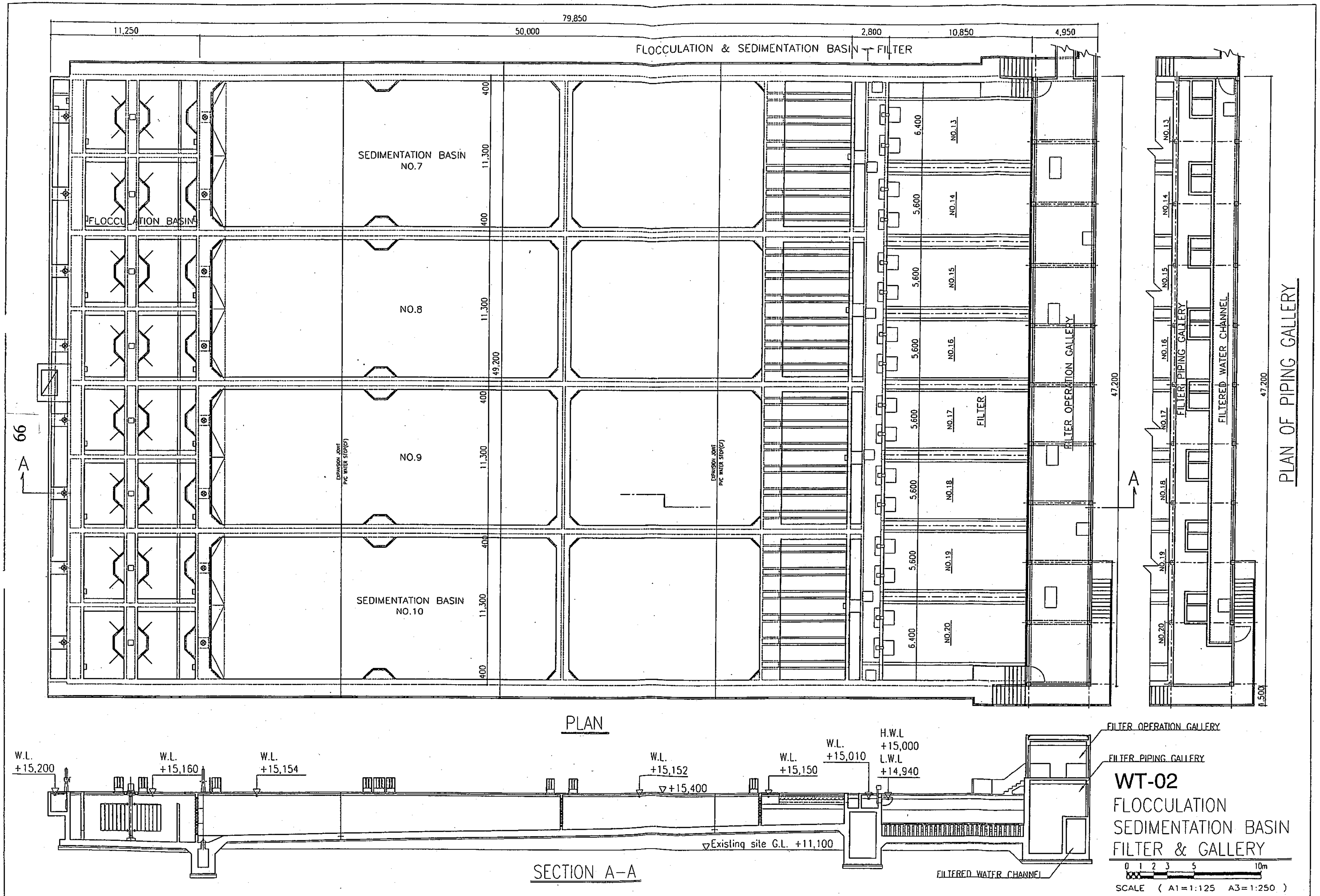


IT-02 GENERAL PLAN

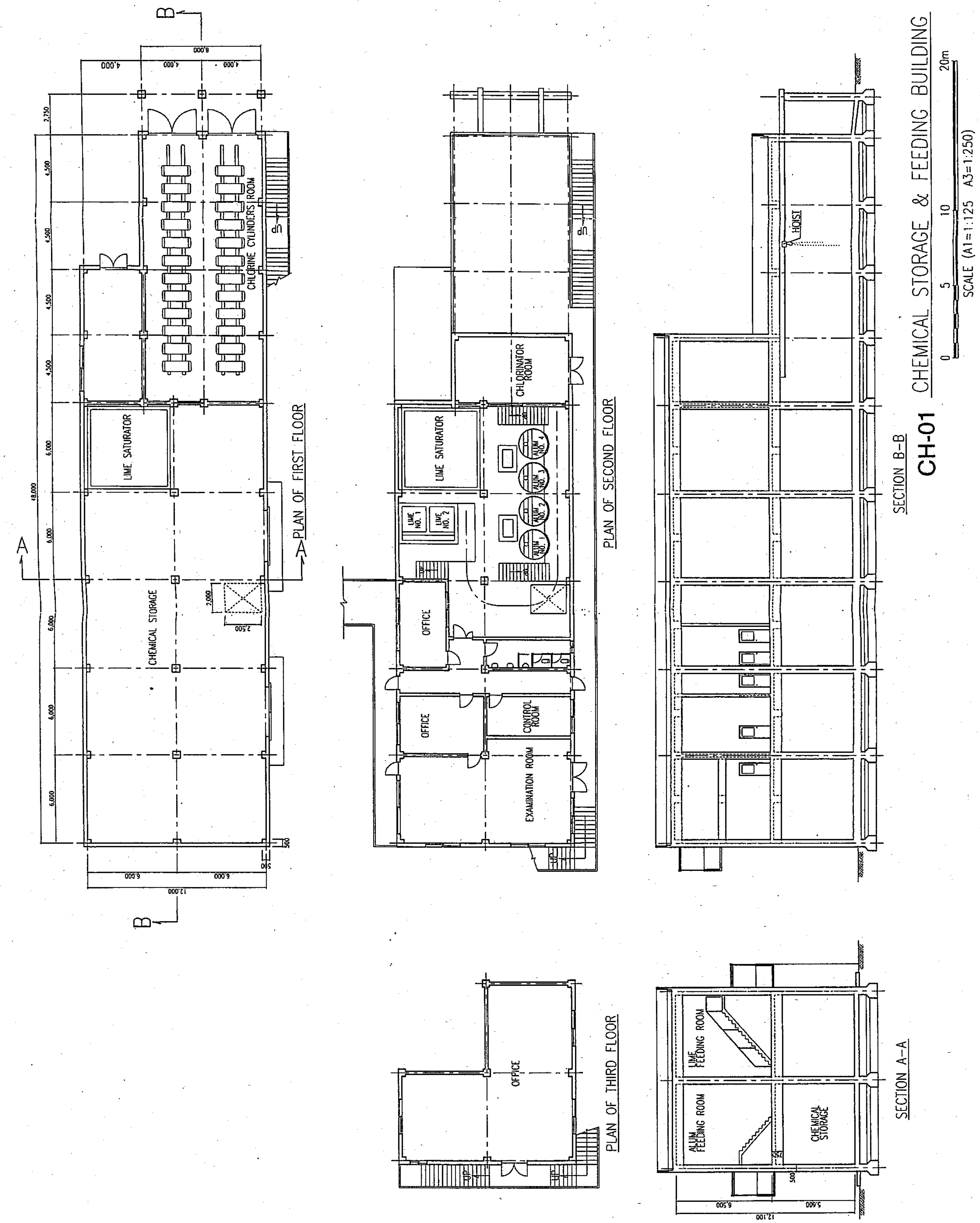


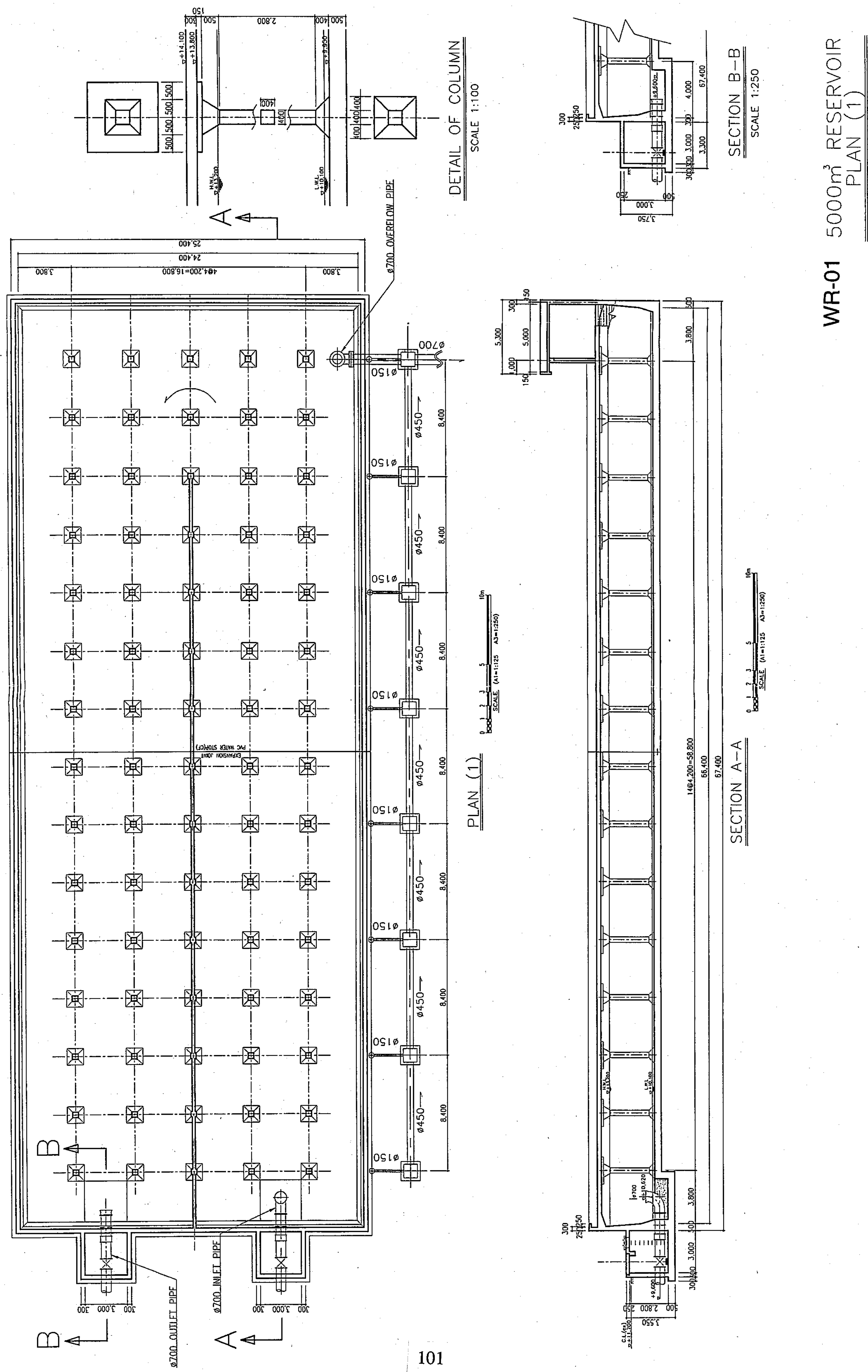
DETAIL OF PIPING


WT-01 RECEIVING WELL
PLAN
SECTION A-A
SCALE (A1=1:75 A3=1:150)
BAFFLE WALL
SUS316 WEIR NOTCH
800X800 H=100 Drain Pit
φ1200 VERTICAL, MANUAL OPERATED RECTI-BATTERFLY VALVE WITH HEAD STOCK
φ1200 FLANGE ADAPTER
VENTILATOR φ150
φ1350
φ1000
φ1100
φ1200
G.L.+11,300
+17,000
W.L.+15,400
+10,400
W.L.+15,656
W.L.+15,500
W.L.+16,000
W.L.+16,050
+11,400
+10,700
+15,600
W.L.+16,400
±11,700
19@250=4,750
22,400

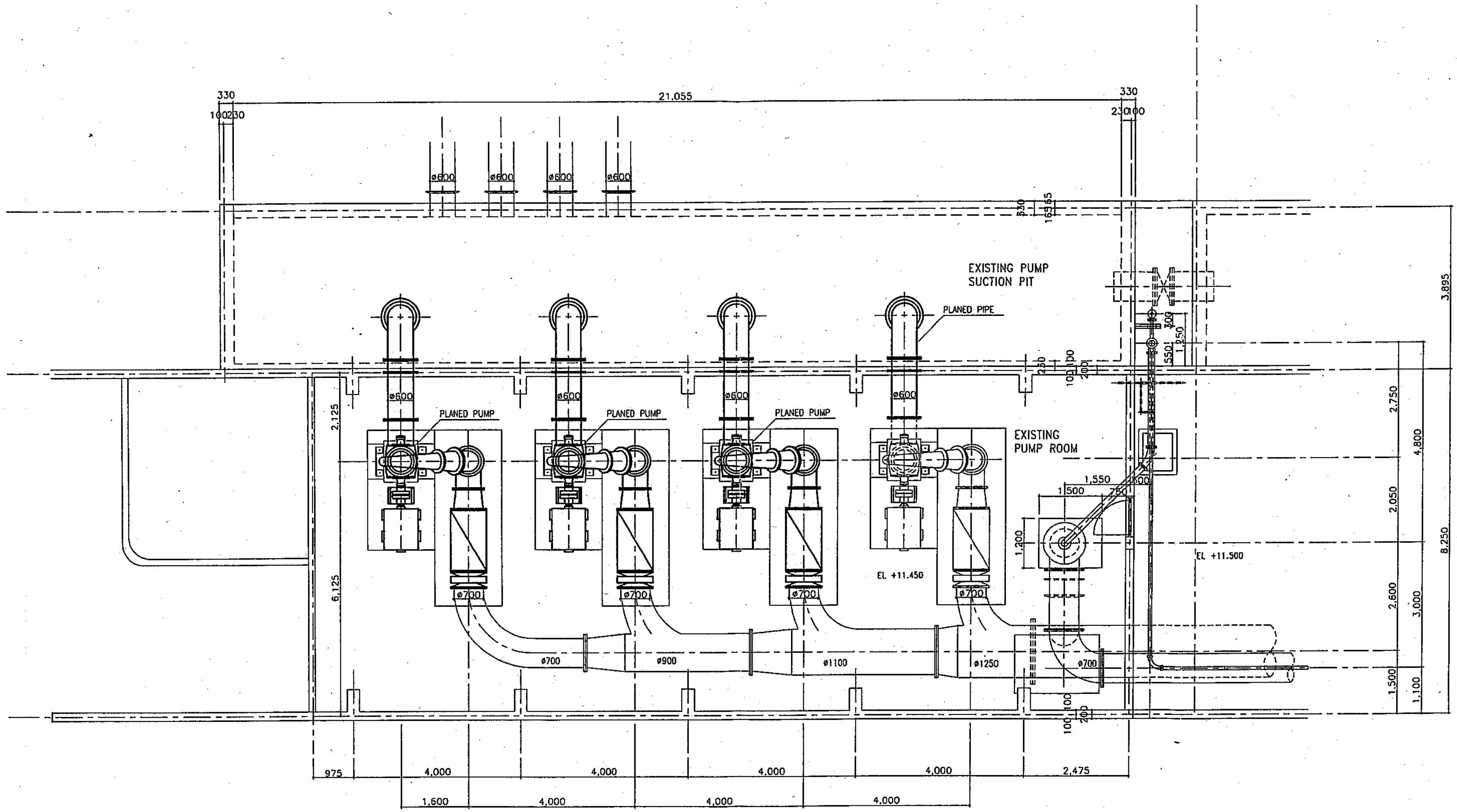


79,850
11,250
50,000
2,800
10,850
4,950
FLOCCULATION & SEDIMENTATION BASIN ⊤ FILTER
FLOCCULATION BASIN
SEDIMENTATION BASIN NO.7
NO.8
NO.9
SEDIMENTATION BASIN NO.10
400
11,300
49,200
EXPANSION JOINT PVC WATER STOP(CF)
NO.13
NO.14
NO.15
NO.16
NO.17
NO.18
NO.19
NO.20
6,400
5,600
FILTER
FILTER OPERATION GALLERY
47,200
FILTER PIPING GALLERY
FILTERED WATER CHANNEL
PLAN OF PIPING GALLERY
1,500
A
PLAN
W.L. +15,200
W.L. +15,160
W.L. +15,154
W.L. +15,152
+15,400
W.L. +15,150
W.L. +15,010
H.W.L +15,000
L.W.L +14,940
Existing site G.L. +11,100
SECTION A-A
FILTER OPERATION GALLERY
FILTER PIPING GALLERY
FILTERED WATER CHANNEL
WT-02
FLOCCULATION
SEDIMENTATION BASIN
FILTER & GALLERY
0 1 2 3 5 10m
SCALE (A1=1:125 A3=1:250)


CHEMICAL STORAGE & FEEDING BUILDING
CH-01
SCALE (A1=1:125 A3=1:250)
PLAN OF FIRST FLOOR
CHLORINE CYLINDERS ROOM
LIME SATURATOR
CHEMICAL STORAGE
PLAN OF SECOND FLOOR
CHLORINATOR ROOM
LIME NO. 1
LIME NO. 2
ALUM NO. 1
ALUM NO. 2
ALUM NO. 3
ALUM NO. 4
OFFICE
CONTROL ROOM
EXAMINATION ROOM
PLAN OF THIRD FLOOR
SECTION B-B
HOIST
SECTION A-A
LIME FEEDING ROOM
ALUM FEEDING ROOM
CHEMICAL STORAGE



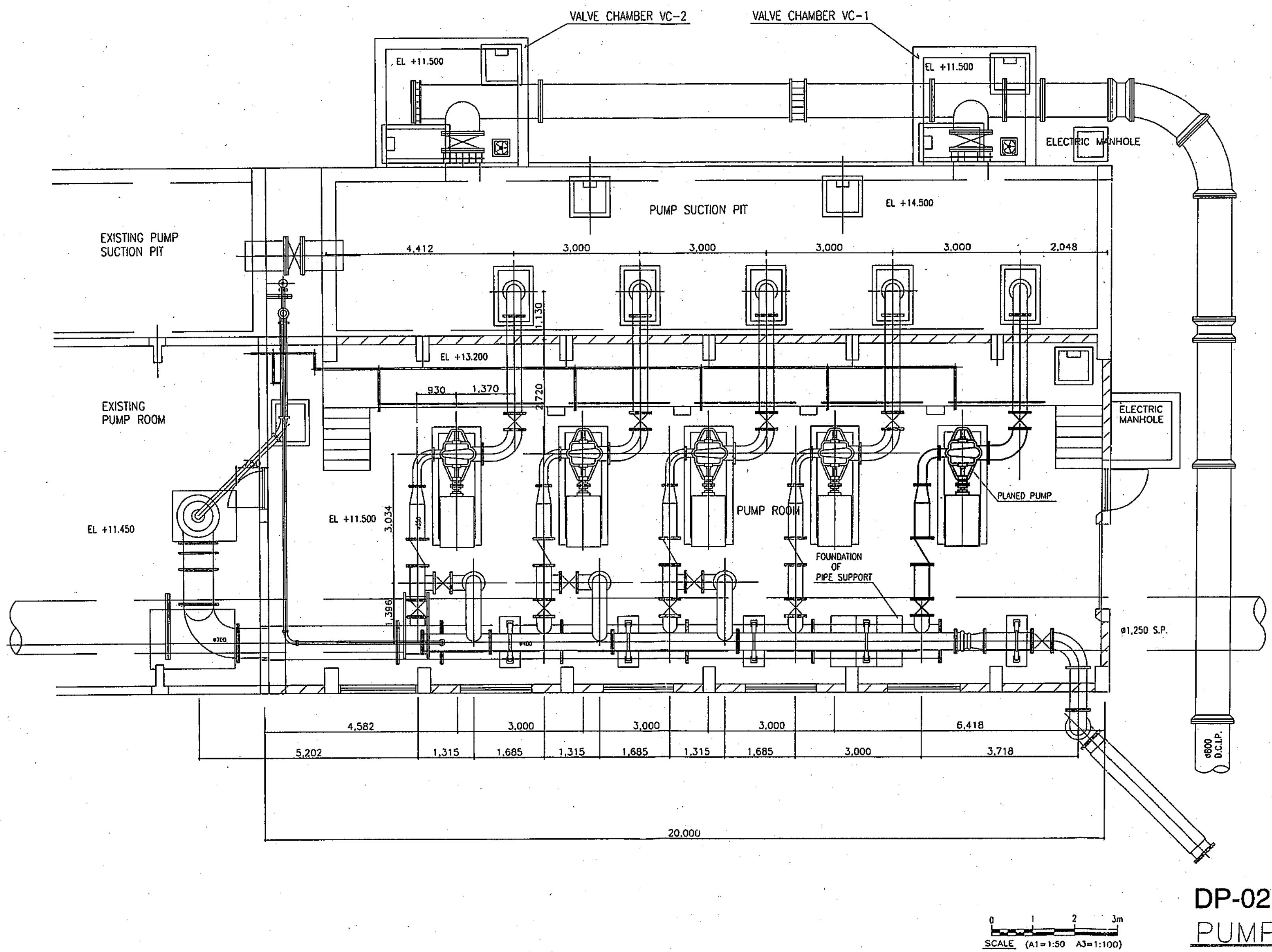
WR-01
5000m³ RESERVOIR
PLAN (1)
DETAIL OF COLUMN
SCALE 1:100
SECTION B-B
SCALE 1:250
PLAN (1)
SECTION A-A
ø700 OVERFLOW PIPE
ø700 INLET PIPE
ø700 OUTLET PIPE
EXPANSION JOINT
PVC WATER STOP(CF)
ø450
ø150
ø700
8,400
25,400
24,400
3,800
4@4,200=16,800
14@4,200=58,800
66,400
67,400



DP-01

PUMP ROOM (1)

SCALE (A1=1:75 A3=1:150)



DP-02
PUMP ROOM (2)

2 - 2 - 6 Implementation Plan

(1)   Implementation Concept

This Project shall be implemented according to the guideline for grant aid of Japan. Hence, the project must be implemented after the Government of Japanese (GOJ) approves the implementation of the project and both the Japanese and Cambodian governments sign the Exchange Notes (E/N).

The following items shall be considered for the project implementation.

1) Implementation organization

Of the Cambodian side, the implementation of the project is the Phnom Penh Water Supply Authority (PPWSA), especially the Department of Technical and Project (DTP). PPWSA shall secure smooth implementation of the project by making necessary arrangements with the organization concerned.

Although the Project contains variety of components and the DTP is managing several other projects, management ability of the DTP is so high that there is no considerable problem regarding management of the Project.

2) Consultant

Japanese consultant shall enter into contract for detailed design and supervision for the project with the implementation organization of the Cambodian side. The consultant shall prepare tender documents and works on pre-qualification and tendering on behalf of the implementation organization and supervise the project.

3) Contractor

Japanese contractor selected by the Cambodian side at open tendering under the guideline of Japanese grant aid shall procure machinery and construction materials including spare parts and construct the facilities of the project.

4) Cut-off of water supply for construction works

During the construction period, time for cut-off of water supply and reduction of water volume supplied from the Phum Prek WTP should be minimized so that influence on activities of the city can be minimized.

5) Implementation schedule

The rehabilitation of the existing facilities requires to cut-off water supply from the existing facilities to the city. To minimize cut-off of water supply, the following sequence of construction works shall be adopted.

1. First: to implement the expansion of the facilities
2. Second: to implement the rehabilitation of the existing facilities

Completion of the expansion facilities will enable to produce treated water 50,000 m^3/day equivalent to 50 percent of the water volume of the existing facilities of Phum Prek WTP. After securing this amount of treated water, the rehabilitation works of the existing facilities will be implemented so that reduction of supply amount of treated water due to the rehabilitation can be minimized.

Chrouy Chagwar WTP (65,000 m^3/day) funded by World Bank is planned to be completed in 2001. After plant operation, water supply volume of the city would be increased by 65,000 m^3/day. This will also ease the cut-off of water due to the rehabilitation.

Construction works of the facilities such as the chemical building that is independent from other construction works should be implemented at the same time of the expansion works.

(2) Implementation Conditions

1) Local construction technology and ability of local contractors

In the Phnom Penh city, there are few large private construction companies, while there are many small construction, architectural, mechanical and electrical companies. The contractor of the project shall use these local companies and can share the works with or refer the works to these companies: such as license procedure, arrangement for workers, procurement of local construction materials, transport and disposal of excavated soil, formwork, reinforcing bar processing, assembly and conveying, and placing and curing of ready mixed concrete.

The technology level and management capacity of these companies, however, is relatively not so high. Japanese engineers and technicians must give directions to local workers and instruct them thoroughly so that the construction can be completed during the terms of work.

When constructing a complex structure and highly waterproof structure such as water reservoir, engineering skills in Cambodia such as processing and assembling of reinforcing bar and formwork is not enough developed. Defect of these engineering skills may affect durability of structure and accuracy of machinery for water treatment, and cause low efficiency of water treatment. Therefore, for the purpose of perfect performance of these works, chief craftsmen for carpentry and reinforcing bar work will be dispatched from Japan.

New water treatment facilities shall be constructed next to the existing water treatment facilities. To avoid dumping carelessly of hazardous construction chemicals into the existing WTP, it is necessary to select reliable local construction companies that PPWSA ensures the ability of works.

2) Procurement of construction machinery

Construction machines that are well maintained are not available so many and can be leased in Cambodia as follows.

・bulldozer
・generator engine
・dump track
・track mixer agitator
・track crane
・mobile concrete pump

(3) Scope of Works

Scope of the works of the Project for the Cambodian or Japanese side is identified by the JICA Study Team as listed in Table 2-2-42.

Table 2 - 2-42 Scope of Works for the Japanese Side and the Cambodian Side

No.		Work Items	Japan	Cambodia
(1) New Construction and Rehabilitation				
1.	Intake pump facilities			
	1.1	Installation of pumps (3 sets, 2200 m^3/hour)	○	
	1.2	Rehabilitation of the intake equipment (intake gates, crane, and water level gage)	○	
	1.3	Rehabilitation of the existing access bridge		○
	1.4	Repainting of the existing intake tower and the access bridge		○
2.	Raw water main			
	2.1	Installation of a raw water main (φ1,200 mm)	○	
	2.2	Installation of an air vessel facility	○	
	2.3	Installation of incidental equipment	○	
3.	New water treatment facilities (50,000 m^3/day)			
	3.1	Construction of a receiving, rapid mixing, and water distribution basin	○	
	3.2	Construction of flocculation basin	○	
	3.3	Construction of sedimentation basin	○	
	3.4	Construction of rapid sand filter	○	
4.	Chemical dosing facilities (150,000 m^3/day)			
	4.1	Installation of feeding equipment for alum sulfate	○	
	4.2	Installation of feeding equipment for slaked lime	○	
	4.3	Installation of feeding equipment for chlorine	○	
	4.4	Construction of a chemical building	○	
	4.5	Supply of equipment and instruments for water quality analysis	○	
5.	Construction of a reservoir (5,000 m^3)		○	
6.	Distribution pump		○	
	6.1	Installation of a new distribution facility (1050 m^3/hour)	○	
	6.2	Renewal of the existing distribution pumps (3 sets, 2100 m^3/hour)	○	
7.	Installation of electric and metering instruments		○	
8.	Installation of connection pipelines including a distribution main		○	
9.	Improvement of the existing sedimentation basin (Installation of baffle wall in the inlet of the basin)		○	
(2) Preparation of construction site etc.				
1.	Necessary permissions for construction of a raw water main, an air vessel facility and the expanded WTP			○
2.	Provision and land leveling of construction site for an air vessel facility and the expanded WTP			○
3.	Removal of the existing intake pump (1 set) for installation of a new pump			○
4.	Removal of the existing air vessel facility			○
5.	Removal of the existing chemical storage house			○
6.	Removal of existing pipes etc. on the construction sites			○
7.	Removal and reconstruction (or relocation) of the guard house for installation of a distribution main			○
8.	Construction of fence along the Boeng Kak Lake, if necessary			○
9.	Preparation of the site for temporary works such as stock yard for materials			○
10.	Preparation of electricity and water for the construction			○

(4) Consultant Supervision

1) Detailed design

About one month after the Exchange of Note is concluded, the detailed design of the project shall start. When the detailed design starts, the detailed site survey should be done for one and half month. Analysis of survey results, the detailed design, and tender document preparation will be done in Japan for five and half months. Total period for the detailed design will be amounted to seven months.

Main works of the detailed design for the project are as follows:

・Drawings of facilities
・Structural analysis
・Arrangement of reinforcement structure
・Calculating capacity of facility
・Hydraulic analysis
・Water treatment machinery capacity calculation
・Electric equipment capacity calculation
・Request and arrangement for cost estimation for civil, architectural, mechanical, electrical and accessory sections
・Comparison and examination of the proposed facilities
・Assistance for examining tender's qualifications
・Preparation of tender documents
・Meetings with tenderers
・Evaluation of tenders
・Assistance in negotiation between implementation organization and contractor
・Assistance for signing of contract between implementation organization and contractor

2) Consultant supervision

The consultant supervisory system for implementing the project as a grant aid project by Japan shall be established by considering the items listed below.

・Understand the contents and history of basic design study
・Understand the grant aid system

・Study the contents of E/N concluded between the two countries
・Study the basic concepts of PPWSA and trends of other aid organizations
・Re-confirm the conditions for implementing work for the Cambodian side requested during the basic design
・Re-check formalities for tax exemption when bringing machinery and materials into the country, and cooperate with the PPWSA so that there is no effect during the work stage
・Study and understand Cambodian customs (National Holidays, etc.)
・Arrange the implementation system considering safety
・Pay attention to avoid failure of operation of existing facility due to the construction of new facilities

At least one consulting engineer must stay at the construction site as resident supervisor for execution supervising during the term of construction.

Resident supervisor for execution supervising is required to be not only a specialist in civil and sanitary engineering, but also a generalist who has knowledge on mechanic and electric and is able to give appropriate advise on any technical aspects.

It is necessary that water treatment, civil, architectural, mechanical, and electrical engineers are dispatched at the necessary stages of the construction. After the construction completes, a water quality analysis engineer must be dispatched at the stage of trial run and adjusting. The engineer is responsible to instruct officers of operation and maintenance in supervising, chemical dosing, and water quality analysis. The works of supervision is categorized into three works.

a) Supervisory duties

・Discussions with concerned personnel before start of work
・Examination and approval of design drawings
・Examination approval of implementation plan
・Inspection of materials and equipment before they are shipped
・Management of progress of works on site
・Witnessing the installation of machinery and equipment
・Inspection of construction progress
・Preparation of monthly progress report
・Witnessing other inspections

・Issue of completion certificates for construction work and payment certificates
・Advising on technical matter
・Inspection and report of completed works
・Default inspection after any year's operation

b) Duties at the completion of work

・Issue the certificates at the completion of work
・Formalities for handing over at the completion of work
・Preparation of final work report

c) Operations and maintenance

・Preparation of operation and maintenance manuals for intake facility and plans for operations and maintenance with PPWSA and the contractor
・Preparation of operation and maintenance manuals for treatment plant and plans for operations and maintenance with PPWSA and the contractor
・Tests and trial run of water treatment plant and intake facility (including water quality monitoring) and training

The engineers and manpowers are required for detailed design and supervision based on above considerations is as listed in Table 2-2-43.

Table 2 - 2-43 Required Engineer and Manpower

	Detailed Design	Supervision
Project manager	1	1 (spot)
Water treatment engineer	1	1 (spot)
Civil engineer	1	1 (spot)
Civil engineer	1	1 (spot)
Architectural engineer	1	1 (spot)
Mechanical engineer	1	1 (spot)
Electrical engineer	1	1 (spot)
Cost estimation	1 (only in Japan)	–
Tender document	1 (only in Japan)	–
Resident supervisor	–	1
Local engineers	–	4

3) Contractor

Contractor shall complete the construction during the terms of work by utilizing local construction companies as subcontractor and employing individual engineers and skilled labors.

The contractor shall dispatch Japanese engineers to Cambodia who have been engaged in similar type of construction work in water treatment plant to manage work schedule, control quality of works and control safety of the subcontractors, local engineers and labors during the construction period.

The type of the engineers and manpowers of the contractor are required for the construction based on scale and contents of the project as listed in Table 2-2-44.

Table 2 - 2-44 Engineers and Man-powers of the Contractor

	No. of persons	Remarks
Manager	1	
Chief clerk	1	
Architect	1	
Civil engineer	2	
Electric engineer	1	
Mechanical engineer	1	
Plumbing engineer	1	
Skilled labor	necessary number	formwork, reinforcing bar processing, waterproofing, electrical and mechanical works
Local engineer	necessary number	Surveyor, Civil engineer, electrical engineer, mechanical engineer, and drafter (CAD)

(5) Procurement Plan

1) Sources for procuring materials and equipment

As a result of investigation of construction materials, following materials are available to procure in Cambodia: sand, crushed stone, brick, wood, ready mixed concrete, cement, reinforced bar, painting materials and fuel oil. Other construction materials should be procured from Japan. Procurement sources of major construction materials are mentioned as below and Table 2-2-45.

1) Reinforcing bars

Amount of reinforcing bars can be imported from China and Thailand. However, quality of Chinese products is at risk because no mill sheet for quality assurance is attached. On the other hand, imported Thai products are at high level in both quality and quantity; therefore, Thai products available in Cambodia are being applied to procure for the project.

2) Cement

Cement is imported from China, Vietnam, and Thailand. In a small amount, Chinese and Vietnamese products are available, but their quality is not uniform. Such cement is not usable for construction of watertight structure such as water treatment plant of this project. Hence, Thai cement is being used for this project because stable and large supplies are available.

In general, it is difficult to keep cement materials appropriate for a long period; therefore, appropriate amount of products must be imported for each stage of the construction work.

3) Equipment for mechanical and electrical equipment

For procuring equipment for construction of water treatment facilities, especially, for mechanical and electrical facilities, Japanese products are imported considering reliability, durability, and supply of spare parts after completion

4) Piping materials and valves

In this project, piping materials need to be applied to large-diameter pipes. Ductile cast iron pipes are used for large-diameter pipe material in standard of PPWSA. Since pumps and control valves used for the existing equipment are made to JIS standard, piping materials and valves connecting to these equipment should be procured from Japan.

Table 2 - 2-45 Source for Procuring Materials and Equipment

Material/Equipment	Source of Procurement		
	Japan	Cambodia	Third Country
1. Construction materials			
Ready mixed concrete		○	
Sand, crushed stone		○	
Cement		○	
Reinforcing bar		○	
Plywood for concrete form		○	
Wood		○	
Steel sheet pile	○		
Pre-stressed concrete pile		○	
Galvanized corrugated steel pile		○	
Painting		○	
Lubricating oil		○	
Fuel oil		○	
Water proofing materials	○		
2. Equipment			
Pumps	○		
Water treatment equipment	○		
Chemical dosing equipment	○		
Electrical equipment	○		
Instrument equipment	○		
Control equipment	○		
Accessories of control equipment	○		
Ductile cast iron pipe	○		
High impact vinyl pipe	○		
Valves	○		
Sand for filter basin		○	

2) Import route for materials

Two marine transport routes from Japan to Cambodia are available.

1. Enter directly a port in Cambodia from Japan
2. Enter a port in Cambodia via Singapore from Japan

Two domestic transport routes from Sihanoukville to Phnom Penh are considerable.

1. Enter Phnom Penh via inland transportation from Sihanoukville Port
2. Enter directly the port of Phnom Penh via the Tonle Mekong by ship

The ship can enter the port of Phnom Penh through the Tonle Mekong. A part of the Tonle Mekong from the mouth of the river to the port of Phnom Penh belongs to Vietnamese territory. In the past, the border has been closed sometimes. If this action is occurred again during the construction period, the ship may not be able to pass through Vietnamese territory and thus cannot reach the Phnom Penh port. To avoid this risk, the transportation route from Sihanoukville shall be adopted for the project transportation route.

The plan for the transportation route of equipment, machinery and construction materials from Japan to Cambodia is shown in Fig. 2-2-13.

(6) Construction Schedule

The implementation of this project consists of three stages: 1) detailed design and preparation of tender documents; 2) approval of tender and award of contract for construction; and 3) procurement of materials and construction works.

This project consists of expansion of water treatment plant and rehabilitation of existing facilities. Construction schedule as shown in Fig. 2-1-2 is planned based on the following periods for major works.

- Preparation for construction and temporary works before the construction works (2 months)
- Expansion of Phum Prek WTP by 50,000 m^3/day (14 months)
- Rehabilitation of existing facilities after completion of expansion (4 months)
- Trial run and adjusting of the WTP (2 months)

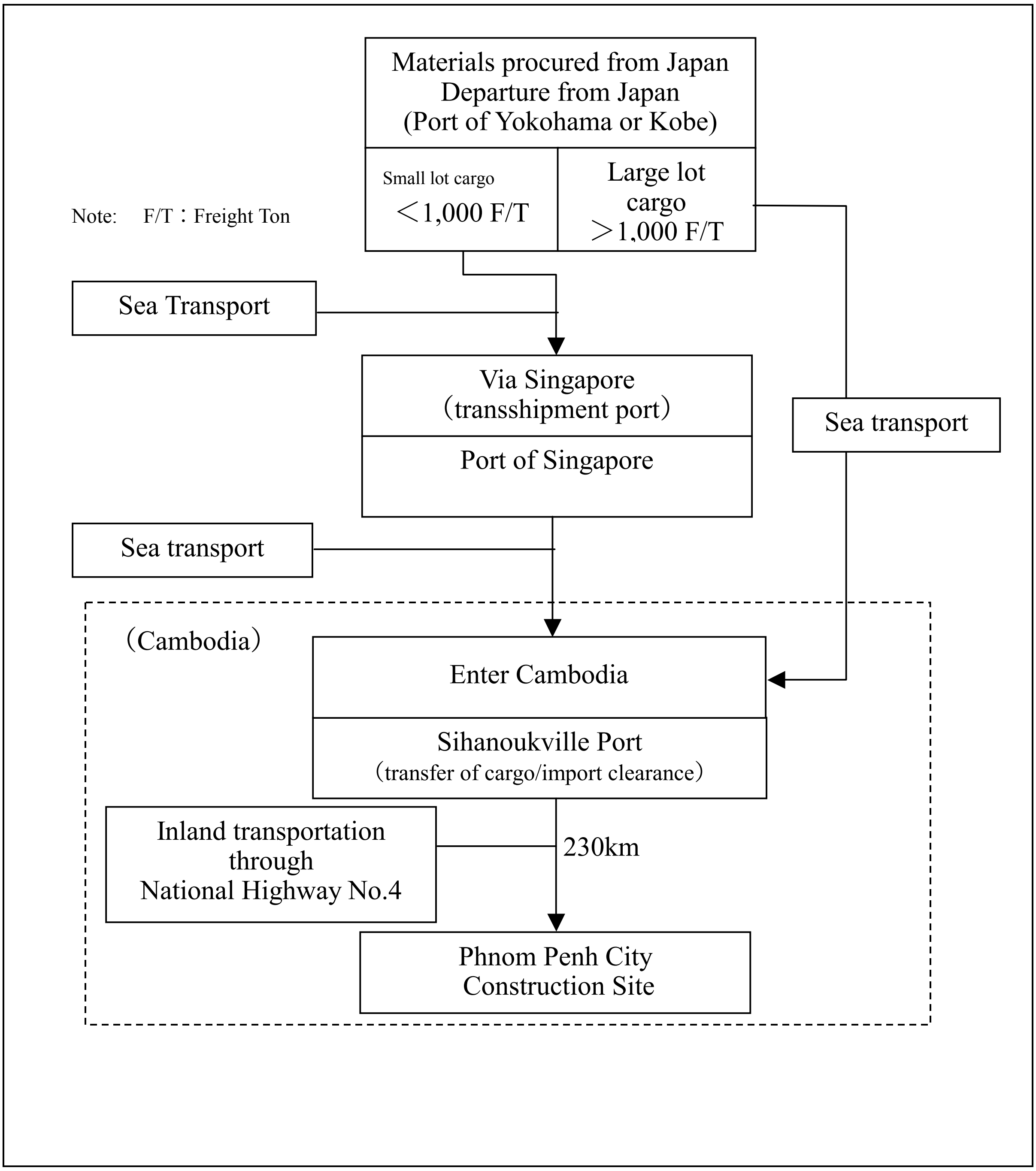


Fig. 2 - 2-13 Transportation Route

2 - 3 Obligations of Recipient Country

The necessary measures and obligation of the Cambodian side for the project are listed as follows.

(1) Items That May Require Cost

① Rehabilitation of the existing access bridge
② Repainting of the existing intake tower and the access bridge
③ Removal of the existing intake pump (1 set) for installation of a new pump
④ Removal of the existing air vessel facility
⑤ Removal of existing chemical storage house at the construction site for the water treatment plant
⑥ Removal of existing pipes etc. on the construction site
⑦ Removal and reconstruction (or relocation) of the guard house for installation of a distribution main
⑧ Construction of fence along the Boeng Kak Lake, if necessary
⑨ Preparation of the site for temporary works such as stock yard for materials
⑩ Preparation of electricity and water for the construction
⑪ Land leveling for construction of the expanded water treatment plant

(2) Items That May Not Require Cost

① Necessary permissions for construction of raw water main, an air vessel facility and the expanded water treatment plant
② Provision of construction site for an air vessel facility and the expanded water treatment plant
③ Securing of access road connected to proposed construction site for the expansion prior to the commencement of construction obligatory for the Japanese side
④ Provision of necessary information and data for the detailed design
⑤ Securing the approval for digging to identify underground structures
⑥ Reaching agreement with residents neighboring the construction site and countermeasure and treatment for traffic regulation
⑦ Provision of disposal site for excavated soil and wastewater
⑧ Countermeasures to cut-off water supply to the city due to the construction works
⑨ Appropriate usage and maintenance and operation of the facilities constructed and equipment supplied by the Japanese grant aid
⑩ Budgeting of the cost required for construction works responsible for the Cambodian side
⑪ Implementation of necessary measures to be taken by the Cambodian side on

condition that the Grant Aid by the Government of Japan is extended to the project such as tax exemption.

(3) Project Cost for the Cambodian Side

The following project costs responsible for the Cambodian side is estimated by the Study Team. Total project cost estimated is US$ 135,800 and will be incurred for 3 years from 2001.

The net income after tax of PPWSA for year 1999 was US$ 451,000 as described in section 2-4 so that PPWSA has enough financial ability to expend the project cost incurred by the Cambodian side.

Table 2 - 3-1 Works and Costs Responsible for the Cambodian Side

Work Items	Costs (US $)
1. Rehabilitation of the existing access bridge	3,000
2. Repainting of the existing intake tower and the access bridge	8,000
3. Removal of the existing intake pump (1 set) for installation of a new pump	2,500
4. Removal of the existing air vessel facility	3,800
5. Removal of existing chemical storage house at the construction site for the water treatment plant	4,000
6. Removal of existing pipes etc. on the construction site	2,500
7. Removal and reconstruction (or relocation) of the guard house for installation of a distribution main	7,000
8. Preparation of the site for temporary works such as stock yard for materials	50,000
9. Construction of fence along the Boeng Kak Lake, if necessary	25,000
10. Preparation of electricity and water for the construction	5,000
11. Land leveling for construction of the expanded water treatment plant	25,000
Total	135,800

2 - 4 Project Operation Plan

(1) Outline of Operation and Maintenance for the Expanded Phum Prek WTP

The divisions responsible for operation and maintenance of the Phum Prek WTP are Division of Phum Prek WTP under the Dept. of Production and Distribution and Division of Water Quality under Dept. of Technical and Project. Division of Phum Prek WTP comprising of 32 staffs is responsible for operation and maintenance of the facilities with 4 shifts (6 hours per shift) and Division of Water Quality is responsible for water quality testing and analysis in the WTP.

Routine operation in the WTP is carried out at intake pumps, chemicals feeding equipment, rapid sand filters and distribution pumps. Basically, the same operational methods as the existing ones are adopted for the new facilities so that operation and maintenance methods are almost the same as the present ones after the completion of the expansion WTP.

(2) Necessary Organization for the Expansion Phum Prek WTP

1) Staffing

The Study Team judged that the number of the present staff assigned is appropriate for operation and maintenance of the existing WTP so that reduction of the staff not required. The expansion facilities can be operated by the same operation methods as it is and it is possible to operate and maintain the expanded WTP with the current staff level. However, following three points are required to improve for more effective operation and maintenance and for improving treated water quality at the WTP.

a) The technology level of operation and maintenance has been raised through training by JICA experts dispatched to PPWSA. The technical level of the present staff is appropriate to conduct ordinary and routine operation and maintenance but is not enough to operate or maintain machines that require more advanced technology. PPWSA shall acquire more advanced technology through training.

b) The main problem of the existing WTP is that the treated water cannot comply the water quality standards. (PPWSA adopts WHO drinking water standards.) To improve the treated water quality and comply the standards, the treatment facility and treatment technology should be improved and raised. The improvement of the treatment facility is proposed in the previous chapter. In terms of technology, PPWSA has no specialist in charge of water treatment in the WTP. Recently, PPWSA assigned an engineer as operation and maintenance specialist in charge of water treatment. However, the engineer is responsible for all WTPs of PPWSA but not specifically for the Phum Prek WTP and has not enough experience and technology. The engineer should be trained more both in Cambodia and other countries in terms of water treatment. The Study Team recommends that PPWSA recruit a specialist for water treatment of the Phum Prek WTP.

c) In addition to having one water treatment specialist, technology level of water quality analysis of the laboratory should be enhanced and necessary skills should be acquired by its staffs to improve treated water quality of the plant. Until October 2000, a Japanese volunteer from JOCV had trained the staffs and thus they acquired basic skills. The JICA Study Team recommends GOJ continue to assist PPWSA to improve technology of water quality analysis by dispatching volunteers or specialists.

Currently, there is no staff who can carry out micro-biological analysis. The Study Team recommends that PPWSA recruit a specialist in charge of micro-biological analysis.

Considering all the above, the necessary organization for the Phum Prek WTP is recommended in Table 2-4-1.

Table 2 - 4-1 Recommended Organization for the Phum Prek WTP After Completion of the Project

Job description	No. of existing staff	No. of Recommended staff	Remarks
1. Phum Prek WTP			
1.1 Maintenance of facilities			
Plant manager (Chief)	1	1	
Mechanical engineer (Vice chief)	1	1	
Water treatment engineer	-	**1**	New
Electrical technician	2	2	
Mechanical technician	1	1	
Technical worker	3	3	
1.2 Operation of facility (4 shift)			
Chief of operator for each shift	4	4	
Control room operators	4	4	
Chemical system operators	4	4	
Sedimentation and filter operators	4	4	
Treated water pumping station operators	4	4	
Intake pumping stations operators	4	4	
Vehicle, security, others	3	3	
Sub-total	**32**	**33**	
2. Dept. of Technical and Project			
2.1 Water quality laboratory (Chemical and biology)	2	**3**	- Train one person as a division chief - a micro-biologist
2.2 Operation and maintenance engineer (Water Treatment)	1	1	
Total	35	37	

2) Roles of staff

Major functions of each unit are assumed as below:

Plant Manager (Chief)

- to be responsible for overall aspects of plant operation and maintenance,
- to be responsible for review and approval of an annual operation plan prepared by the deputy plant manager and other reports prepared and requests filed by the relevant units,
- to provide General Manager/Deputy General Manager in PPWSA office with necessary

information and data on plant operation and maintenance periodically and/or when required,
- to evaluate staff performance periodically based on information provided by the unit leaders,
- to make review of the present organization periodically with particular attention to internal information system, task requirements and staffing,
- to attend weekly or monthly meetings in PPWSA office,
- to chair monthly or weekly technical meetings between the units in Phum Prek WTP to enhance technology transfer between the staff, and
- to develop programs to raise technology level of the staff.

Vice Chief

- to assist Plant Chief in carrying out his responsibilities for overall aspects of plant operation and maintenance,
- to prepare draft annual operation plan for perusal of Plant Chief based on information provided by each unit,
- to modify annual operation plan whenever necessary and instruct the modified operation to each unit, report it to Plant Manager, and
- to make review of various reports prepared/requests filed by the relevant unit prior to submission of Plant Chief.

Mechanical and Electrical Engineer

- to conduct periodical overhaul of all electrical and mechanical equipment and repair when any damages or defects are found,
- to grasp volume of intake, treated and distributed water and instruct operation unit about necessary measures
- to provide technical information regarding electrical and mechanical equipment installed in the plant to other units for their understanding,
- to keep records of maintenance for submission to Plant Chief, and
- to take necessary procedures for repair order to the local workshops when repair works are found beyond capability of the staff.

Water Treatment Engineer

- to be responsible for monitoring operation of overall treatment process in the plant
- to formulate a water treatment operation plan in accordance with an annual overall operation plan of the plant,
- to monitor chemical feeding rates, flocculation conditions and settled sludge,
- to analyze water quality data tested by the laboratory and water flow data recorded by the plant operators,
- to study optimum operation methods for water treatment and instruct the operation unit on it, and
- to study necessary countermeasures to degradation of treated water quality and instruct the operation unit on it.

Water Quality Laboratory

- to conduct routine laboratory testing in accordance with water testing manuals to ensure safety of treated water,
- to keep testing result in a computer,
- to provide information on required chemical feeding rate to the relevant units,
- to provide information on testing results with technical comments to Plant Chief and Vice Chief,
- to conduct laboratory testing for specific purposes when needs arises, and
- to take necessary measures for maintaining testing equipment, glassware, chemical agents and other miscellaneous consumable/assets in normal conditions to ensure appropriateness of their quality and stock.

Operation of the Facilities

- to achieve effective operation and control of raw water pumping station, distribution pumping station and other miscellaneous mechanical and electrical equipment/devices under direction of Plant Chief or Vice Chief;
- to monitor and control raw water intake rate and water production rate along with the production targets set up by PPWSA;
- to keep clean and sanitary in the plant yard and buildings
- to endeavor to minimize water losses in the plant
- to periodically carry out cleaning of each basin and filter backwashing under direction of Plant Chief or Vice Chief;
- to keep daily records in the specified format including such items as intake flow rate,

production flow rate, pump operation, chemical feeding rate, chemical and power consumption, water level of the reservoirs, etc.

PPWSA shall establish the proposed organization for the Phum Prek WTP mentioned above considering the following recommendations before the completion of the Project.

1) to acquire basic skills and technology required for each technical field, especially when Japanese contractor transfers the technology of operation and maintenance during the trial operation period of the expanded WTP,
2) to allocate budget required for appropriate operation and maintenance of the expanded WTP,
3) to prepare and carry out training programs for the staffs of the WTP in the plant site and the outside,
4) to evaluate skills and technology level of each staff and prepare technology and skill development programs, and
5) to employ engineers or train existing engineers in charge of water treatment and more advanced water quality testing.

(3) Operation and Maintenance Plan

1) Operation flow of water treatment plant

The basic items to be controlled are intake flow rate, distribution flow rate and chemical feeding rate. To achieve planned flow rates, the appropriate operation according to fluctuations in the river water level, raw water quality and water demand of the city is needed. Basic contents and flowchart for control and monitoring of the expanded WTP are shown in Table 2-4-3, Figure 2-4-1 and Figure 2-4-2.

Table 2 - 4-2 Control Contents at the WTP

Control Item	Variable Item	Monitoring Item	Control Contents
Intake and raw water flow rate (daily)	Water level of Tonle Sap varies by around 10 m throughout the year. An intake flow rate of raw water which corresponds to the planned production rate is required.	・Tonle Sap water level ・Incoming flow rate at the inlet of the WTP	Control flow rate by the number of operating pumps and sluice valves before the WTP.
Transmission and distribution flow rate (continuously or hourly)	Water demand in the city varies in continuously	・Water level of distribution reservoir and tower ・Transmission and distribution flow rate	Control by the number of operating pumps.
Chemical feeding rate (daily)	Fluctuations in raw water quality, especially in turbidity is extreme.	・Incoming water flow rate to the WTP ・Raw water quality	Set the chemical feeding concentration according to raw water quality, and feed appropriate rate of chemicals according to the intake flow rate.

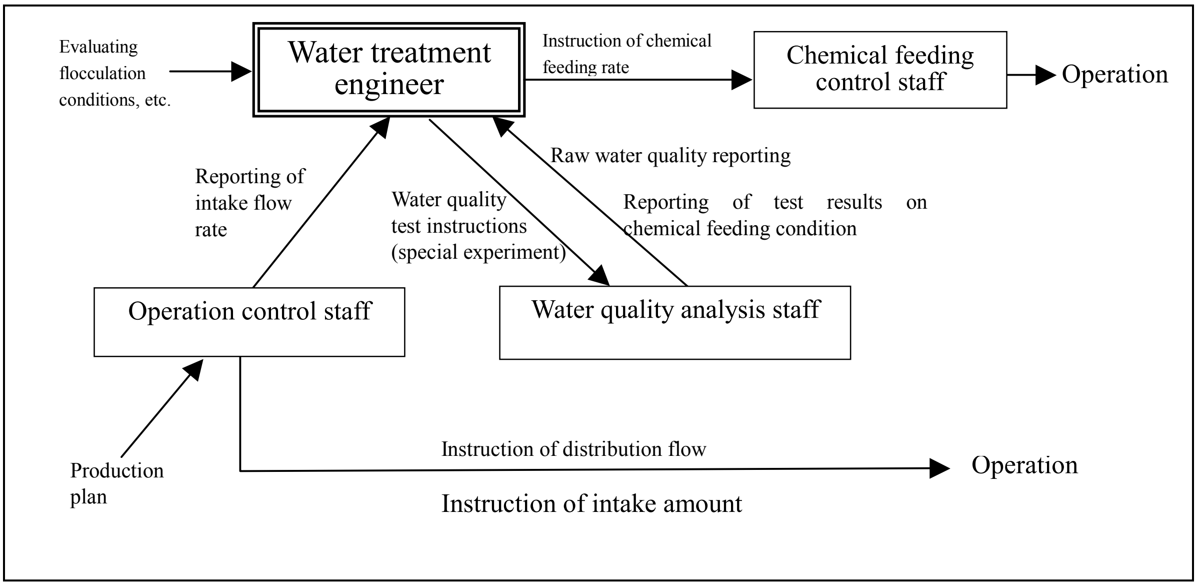


Fig. 2 - 4-1 Basic Flow of Water Treatment Facility Operation

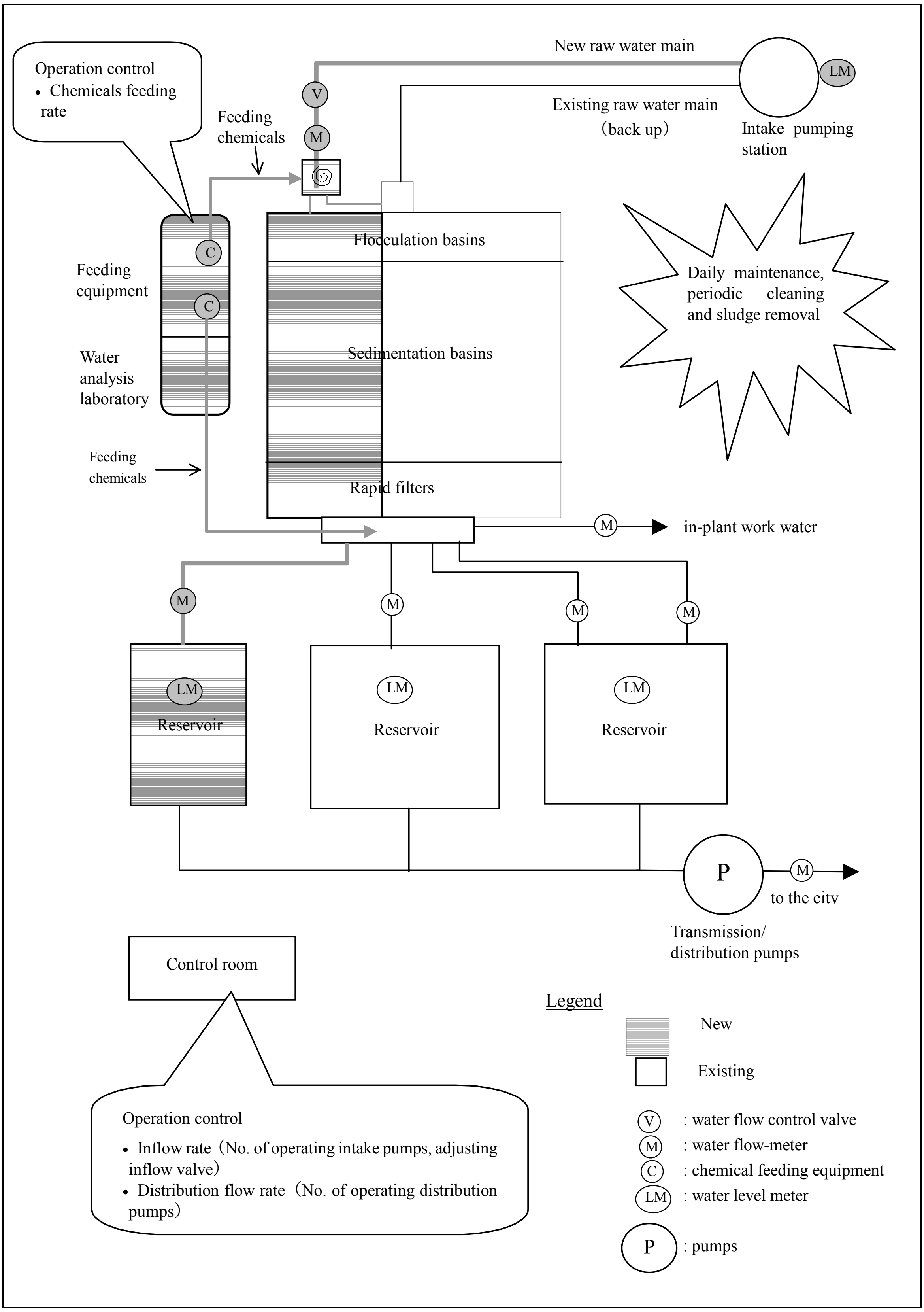


Fig. 2 - 4-2 Major Control Items in the Expanded Phum Prek WTP

2) Operation and maintenance items

Operation and maintenance items for the major facilities and equipment at the WTP following the expansion are shown in the Table 2-4-3. The transfer of technology, including detailed operation and maintenance procedures, shall be carried out by the Japanese contractor via on-the-job training (OJT) and manuals made by the contractor during handing over of the facilities following the completion of the Project.

Table 2 - 4-3 Operation and Maintenance Items of Major Facilities and Equipment

Facility/Equipment	Operation Item	Maintenance Item
Intake pump	Control of number of operating pumps	Periodic maintenance of equipment
Raw water main	—	Sludge removal, cleaning
Inflow rate adjustment valve	Adjustment of inflow rate	
Receiving well	—	Sludge removal, cleaning
Rapid mixing basin	—	Sludge removal, cleaning
Flocculation basin	Adjustment of flocculator speed	Sludge removal, cleaning, periodic maintenance of equipment
Sedimentation basin	—	
Rapid sand filter	—	Periodic maintenance of equipment, cleaning, change of filtration sand
Chemical feeding	Chemical feeding rate (coagulant, alkali, chlorine)	Periodic maintenance of equipment
Distribution reservoir		Cleaning
Transmission and distribution pump	Control of number of operating pumps	Periodic maintenance of equipment

3) Spare parts and water quality analysis reagents

Spare parts supplied in the Project shall not include parts that can be routinely obtained in the local market, e.g. expandable and fabricated parts such as round bars, etc. In the Project, roughly two-year supply of locally unavailable spare parts for broken down machinery and electrical equipment shall be included. It will be necessary for PPWSA to independently secure the necessary budget for additional spare parts and carry out their procurement after this reserve supply of spare parts has been exhausted. Project equipment which includes spare parts is indicated below.

① Intake pump equipment
② Flocculation mechanical equipment
③ Filter bed mechanical equipment
④ Chemical feeding mechanical equipment
⑤ Distribution pump equipment

Reagents for three-month water quality analysis shall be supplied.

4) Repair and renewal cost

It is necessary for PPWSA to secure the necessary funds for equipment repairs. Furthermore, the service life of machinery and equipment is 15-20 years, and it will be necessary to raise funds for renewal in a planned way.

5) OJT by the Japanese contractor for the WTP

It is necessary for PPWSA to carry out appropriate operation and maintenance following the completion of the Project in accordance with operation and maintenance manuals and technology transferred via OJT by the Japanese contractor.

(4) Operation and Maintenance Costs

Items contributing to increase in operation and maintenance costs following the completion of the Project are expenses for power, chemicals, repairs spare parts and personnel and depreciation costs. Costs for expanding the service area and increasing service connections to distribute the increased treated water from the expanded WTP will be an additional cost. In terms of income, additional revenue will come from selling the increased water volume.

Annual operation and maintenance costs due to expanded Phum Prek WTP are examined below.

a. Power cost and chemicals expenses

Annual power and chemicals consumption and their costs with the expansion of Phum Prek WTP are shown in Table 2-4-4. The estimation is based on electricity tariff increase in August 2000.

Table 2 - 4-4 Cost Estimation of Operation and Maintenance of Expanded WTP (Electricity and chemicals)

		Annual Consumption	Annual Cost Estimate
Electricity	Water treatment	834,000 kWh/year	400 million Riel
	Water intake	4,862,000 kWh/year	2,334 million Riel
	Water transmission and distribution	8,760,000 kWh/year	4,205 million Riel
	Subtotal	14,456,000 kWh/year	6,939 million Riel
Chemicals	Aluminum Sulfate	1,359 tons/year	326,000 US $
	Slaked lime	289 tons/yea	35,000 US $
	Chlorine gas	144 tons/year	158,000 US $
	Subtotal	–	519,000 US $ = 1,998 million Riel
Total		–	8,937 million Riel

The estimation in Table 2-4-4 is based on the following assumptions.
1 US $ = 3,850 Riel
Power tariff : 480 Riel/kWh = 0.09 US $/kWh (for Phum Prek WTP)
Aluminum Sulfate : 240 US $/ton (including transportation cost)
Slaked lime : 120 US $/ton (including transportation cost)
Chlorine gas : 1,100 US $/ton (including transportation cost)

b. Salary

Two additional staffs for the WTP, a water treatment engineer and a water quality engineer, are required after the complementation of the Project. This will increase the plant expenses by an additional amount of 6,502,000 Riel/year based on an average wage of 3,251,000 Riel per person in 1999.

c. Repair and spare parts expenses

Based on a typical water treatment plant in Japan, a ratio of annual repair and spare parts expenses to the total assets subject to depreciation is about 1 %. Applying this ratio to the facilities constructed in the Project, the additional expenses for repair and spare parts are estimated at 465,500,000 Riel/year.

d. Depreciation cost

Additional depreciation cost is estimated at 1,750,000,000 Riel/year by depreciating the facilities constructed in the Project in 50 years.

(5) Financial Feasibility of the Project

a. Current financial conditions

Major financial indicators for 1999 for grasping the usage characteristics of Phum Prek WTP and financial conditions of PPWSA are compared with corresponding data from major cities in Japan in Table 2-4-5. The operating rate of the WTP is extremely high. This suggests that facility is effectively utilized. However, the capacity of the facility is insufficient from demand point of view. The revenue water ratio is low compared to Japan and has possibilities for improvement. In spite of the low revenue water ratio, the ratio of current revenue to current expenses is extremely high.

Table 2 - 4-5 Usage Characteristics of Phum Prek WTP, Analysis of the PPWSA (1999) and Comparison with Large Cities in Japan

Description	Ratio		Formula
	PPWSA/Phum Prek WTP	Large cities in Japan	
Facility usage ratio (1) for Phum Prek WTP *	91.2 %	84.0 %	Daily average distribution volume / Daily maximum distribution volume
Facility usage ratio (2) for Phum Prek WTP *	91.6 %	66.4 %	Daily average distribution volume / Maximum distribution capacity
Availability factor for Phum Prek WTP *	98.6 %	79.1 %	Daily maximum distribution volume / Maximum distribution capacity
Revenue water ratio	51 %	87.6 %	Annual revenue water volume / Annual total distribution volume
Unit price per revenue water	767 Riel	161.3 yen	Annual water sales / Annual revenue water volume
Unit costs per revenue water	886 Riel	188.4 yen	Total operating costs / Annual revenue water volume
Service population per staff *2	1,275 person/staff	1,704 person/staff	Served population / Number of staff
Revenue water per staff	50,000 m^3/staff	233,454 m3/staff	Annual revenue water volume / Number of staff
Current ratio	457	145	Current assets / Current liability
Return on net asset	0.50	2.29	Net income / Current liability
Current balance ratio	110.5 %	98.3 %	Total revenue / Total expenses

Notes: Large cities in Japan includes ordinance-designated cities and Tokyo.
*1: Values for Phum Prek WTP based on average monthly data
Assuming 520,000 as the service population equivalent to the present urban population.

b. Financial analysis after the completion of the Project

Concerning the expected financial balance of PPWSA following the completion of the Project, the case of project implementation (With Project: W/P) is compared with the case of no project implementation (Without Project: WO/P) to examine the feasibility for the Project and the improvement in the financial balance after the Project. The following four cases were examined for year 2005 based on the preconditions described below.

Case	Project implementation	Revenue water ratio	Abbreviation
A	no project implementation	80%	WO/P 80%
B	project implementation	80%	W/P 80%
C	no project implementation	70%	WO/P 70%
D	project implementation	70%	W/P 70%

i) Analysis preconditions

- Financial balance analyzed for 2005 (following completion of the Project)
- Analysis carried out on the basis of financial conditions in 1999.
- Costs of Phum Prek and Chamcar Morn WTP included.
- Impacts from other projects (completion of Chrouy Changwar WTP, etc.) not included.
- Average water tariff is assumed to be the same as the present one (767 Riel/revenue water amount m^3).
- The electricity tariff increase in August 2000 is considered.
- Operating rate of the Phum Prek WTP in 2005 shall be 90%.

ii) Revenue forecast

Based on the above preconditions, annual total revenue from water sales will be 34,266,000,000 Riel/year and 29,982,750,000 for 80 % and 70 % revenue ratios, respectively, as shown below:

(150,000 + 20,000) (m^3/day) x 0.9 x 365 (days/year) x 0.8 x 767 (Riel/revenue water amount m^3)
= 34,266,000,000 Riel/year
(150,000 + 20,000) (m^3/day) x 0.9 x 365 (days/year) x 0.7 x 767 (Riel/revenue water amount m^3)
= 29,982,750,000 Riel/year

Considering the present values, revenues from house connections and other sources are estimated as shown in Table 2-4-6.

c. Expenses

- Expenses for power, chemicals, repair and spare parts and depreciation were estimated in the previous section.
- Salary, costs for labor & sub-contract work, vehicle and equipment costs, administration expenses and other allowances are estimated using the ratio of each expense to total revenue of 1999.
- Disposal assets, bad debt, and turnover tax are assumed to be zero.
- Interest on payment is the same as the present value.
- Sales tax is estimated as 20 % of the net income before tax.

iv) Results of financial feasibility analysis

The expected financial balance of PPWSA following the Project completion, computed based on the assumptions mentioned above, is shown in Table 2-4-6.

Main operation and maintenance costs that increase after the completion of the Project are expenses for repair and spare parts, chemicals, power and depreciation. The total increase in operation and maintenance costs per year is 8,100 million Riel (US$ 2.1 million) and the increase in revenue will be 11,600 million Riel (US$ 3.0 million). Hence, the increase in operation and maintenance costs can be covered by the increase in revenue.

Current account profits for all cases considered above increased over the corresponding 1999 figures. PPWSA, which was already in profit during 1999 and is a sound organization, will be able to further increase current account profit by raising the revenue water rate and the supply volume.

Based on this improved financial basis, PPWSA can improve its technical capabilities, introduce sophisticated technologies, raise interest on payments of past projects, purchase appropriate spare parts, etc. As a result, further development of the water supply system of the Phnom Penh city can be expected.

Table 2 - 4-6 Forecast of Financial Balance for PPWSA after the Completion of the Project in 2005

（Unit:1000 Riel ）

	Year Description	1999 Actual	2005 W/OP80%	W/P80%	W/OP70%	W/P70%
I	**REVENUE**					
1	Water sales	15,654,638	24,188,000	34,266,000	21,164,500	29,982,750
2	House connection	2,141,647	1,000,000	2,500,000	1,000,000	2,300,000
3	Other revenue	2,451,237	500,000	500,000	500,000	500,000
	TOTAL OPERATING REVENUE	**20.247,522**	**25,688,000**	**37,266,000**	**22,664,500**	**32,782,750**
II	**EXPENSES**					
01	Salaries	1,326,394	1,682,794	2,441,257	1,484,728	2,147,564
02	Labor cost & sub-contract work	900,199	1,142,081	1,656,836	1,007,657	1,457,512
03	Maintenance	305,197	387,203	852,703	341,629	807,129
04	Transportation & Equipment	181,603	230,399	334,244	203,281	294,033
05	Chemical for treated water	932,099	1,414,530	2,255,597	1,414,530	2,255,597
06	Power consumption	3,784,061	5,189,569	8,325,880	5,189,569	8,325,880
07	Administrative expenses	481,754	611,201	886,679	539,262	780,008
08	Other allowance	231,492	293,694	426,066	259,126	374,809
09	Disposal assets	4,446	0	0	0	0
10	Other	262,717	333,309	483,536	294,078	425,365
	TOTAL OPERATING COST	**8,409,962**	**11,284,780**	**17,662,798**	**10,733,860**	**16,867,897**
	Net Income (Loss) before Depre.	**11,837,560**	**14,403,220**	**19,603,202**	**11,930,640**	**15,914,853**
11	Bad Debt	160,085	0	0	0	0
12	Depreciation	8,294,755	8,294,755	10,044,755	8,294,755	10,044,755
	Net Income (Loss) before Int.	**3,542,805**	**6,108,465**	**9,558,447**	**3,635,885**	**5,870,098**
13	Turnover tax	0	0	0	0	0
14	Interest	1,212,299	1,212,299	1,212,299	1,212,299	1,212,299
	TOTAL EXPENSES	**18,077,101**	**20,791,834**	**28,919,852**	**20,240,914**	**28,124,951**
	Net Income (Loss) before Tax	**1,895,330**	**4,896,166**	**8,346,148**	**2,423,586**	**4,657,799**
15	**Income Tax**	379,066	979,233	1,669,230	484,717	931,560
	Net (Loss) Profit	**1,516,264**	**3,916,933**	**6,676,918**	**1,938,869**	**3,726,239**

CHAPTER 3

PROJECT EVALUATION AND RECOMMENDATIONS

Chapter 3 Project Evaluation and Recommendations

3 - 1 Project Effects

(1) Direct Effects

After completion of the Project, the following effects will be obtained.

- By increase in the production of the treated water by 50,000 m^3/day and by improvement in the treated water quality of the existing WTP, 545,000 residents will be able to obtain necessary amount of safe water. Thus, the water service coverage in the area covered by the Phum Prek WTP will increase from the present value of 60 % to 100 %.
- Most of the present non-served population are poor people. The water supply conditions for poor people will improve substantially, if they are given priority in receiving more water through the Project.
- The amount of water that can be used for the commercial, industrial and public activities will increase from 19,100 m^3/day to 48,000 m^3/day.
- The industrial and public sector can also obtain drinkable water directly. This is especially beneficial for restaurants and schools.
- The distributed water can only be supplied up to the first floor with the present water service pressure. The service pressure will increase to 2.5 ~ 3.0 kg/cm^2 after the completion of the Project. This service pressure will be sufficient to directly supply water to apartments at fifth floor and to the edge of the service area. As a result, all residents of the service area will have the water supply directly from the piped water system without using individual storage tanks and pumps or carrying the water to the upper floors manually.

(2) Indirect Effects

1) Improvement in sanitary conditions of 545,000 city residents

Supply of necessary amount of sanitary safe water to the residents will help in decreasing the number of patients suffering from water borne diseases (which is presently about 5,000 persons per year), decreasing the infant mortality rate, saving medical expenses of the Phnom Penh municipality and the residents, and increasing work productivities due to better health of people. The above 5,000 patients per year are only based on the medical records in the hospitals. It is reported by the municipality sanitation department that there are many poor patients suffering from water born diseases who cannot afford to visit a hospital.

2) Improvement in living standards of poor people and poverty alleviation

The most of the poor people, who do not currently have any PPWSA water service connection, not only use unsanitary water but also purchase extremely expensive water from the wholesalers with prices 6 to 23 times higher than the PPWSA water tariff. According to the municipality sanitation department, many of the poor people are suffering from water borne diseases, especially gastroenteric disorder caused by drinking unsanitary water. The living standards and healthy conditions of poor people will be improved drastically through the supply of necessary amount of sanitary safe water at cheaper prices.

3) Enhancements in management, operation and maintenance system of PPWSA

The financial capability of PPWSA will be improved by increase in profits from sales of water. As a result, PPWSA will be able to improve its technological and management capabilities, carry out appropriate operations and maintenance of the facilities by timely purchase of spare parts, introduce advanced technology and expand the water service area.

4) Benefits for other water treatment plants

The water quality analysis laboratory at the Phum Prek WTP plays a central role in water quality analysis not only for the PPWSA but also for Cambodia as a whole. Water quality analysis of local water supply authorities in other parts of Cambodia is carried out in this laboratory on a contract basis. Therefore, the improvement of laboratory skills and technology at the Phum Prek WTP will contribute to the improvement of potable water quality in other parts of Cambodia.

The present technology level of PPWSA in terms of water treatment is not very advanced. The water treatment technology will be enhanced through the Project. If PPWSA transfers the acquired technology to local water supply authorities in other parts of

Cambodia, improvements in water treatment technology and potable water quality in entire Cambodia can be expected in future.

5) Enhancement in the development of capital city

The commercial, industrial and public sectors are concentrated in the Phnom Penh city. However, sound development as a capital city has been restricted to a large extent due to current water shortage. Increased amount of treated water produced at the Phum Prek WTP will alleviate the water shortage, thereby facilitating sound development of the city.

3 - 2 Recommendations

The Cambodian side is required to carry out the following recommendations for an effective execution and generation of the best results from the Project.

(1) Minimize effects of reduction and cut-off of water supply during the construction

After completion of the expansion, existing facilities will be rehabilitated. During the rehabilitation, cut-off of water supply and reduction of water volume supplied from the Phum Prek WTP are temporally necessary. Duration for cut-off of water supply and reduction of water volume should be minimized so that city activities and demand of the residents are not affected significantly. The Japanese side will use appropriate construction methods to minimize the time for cut-off and reduction of water supply, and the Cambodian side should take necessary measures including the utilization of treated water from other water treatment plants and appropriate public relation measures with the residents.

(2) Maintain continuous operation of the existing WTP during the construction

PPWSA is required to maintain continuous operation of the Phum Prek WTP and water supply to the city during the construction period.

(3) Complete water distribution network in the urban area

It is necessary to complete water distribution network in the urban area to supply the increased treated water from the Phum Prek WTP to the residents. It is planned that the construction of the distribution network will complete during year 2001 and such plans should be worked out as planned.

(4) Promote increase in service connections

In addition to the development of distribution network, increase of service connections is necessary to increase water supply to the residents. PPWSA is required to promote the new service connections to the population currently without water-supply connections through appropriate publicity. In particular, service connections for the poor people should be increased through publicity of advantages of PPWSA water supply. PPWSA is currently taking several measures to easily connect poor people to PPWSA water supply. PPWSA is required to continue to act on these measures.

(5) Allocate necessary budget for spare parts as planned

In the Project, roughly two-year supply of locally unavailable spare parts for broken down machinery and electrical equipment will be included. It will be necessary for the PPWSA to independently secure the necessary budget and carry out the procurement of spare parts after the supply has been exhausted.

(6) Reduce leakage ratio and increase revenue water ratio

PPWSA is required to enhance its financial capability to secure necessary budget for operation and maintenance costs including spare parts expense as described above. PPWSA has a plan to increase revenue water ratio to 80 % and is required to accomplish the target by continuously implementing the plan.

(7) Improve technology for operation and maintenance of the water treatment plant

Best effects of the Project can only be achieved by properly maintaining the WTP constructed by the Project. GOJ has dispatched Japanese experts, third country experts and a Japanese voluntary expert from JOCV, and they have transferred operation and maintenance technology of the WTP including water quality analysis. PPWSA itself has dispatched 29 trainees during the past three years to other countries, including Japan, to improve the operation and maintenance technology and the management system.

PPWSA should make every effort to acquire the appropriate technology for operation and maintenance of the expanded Phum Prek WTP by continuous training activities.

One of the main objectives of the Project is to improve the treated water quality of the existing WTP. To improve the quality of the treated water, improvement in technology for water treatment and water quality analysis is essential. PPWSA doesn't have any water treatment engineer and micro-biologist for water quality analysis. PPWSA is required to secure appropriate engineer in these fields by recruiting new staff or training existing staff. GOJ is required to assist PPWSA in improving water treatment technology by dispatching water treatment engineer from Japan or from a third country such as Thailand.