KINGDOM OF CAMBODIA
PHNOM PENH WATER SUPPLY AUTHORITY (PPWSA)

THE DATA COLLECTION SURVEY ON WATER SUPPLY DEVELOPMENT IN PHNOM PENH CAPITAL IN THE KINGDOM OF CAMBODIA

FINAL REPORT

FEBRUARY 2022

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

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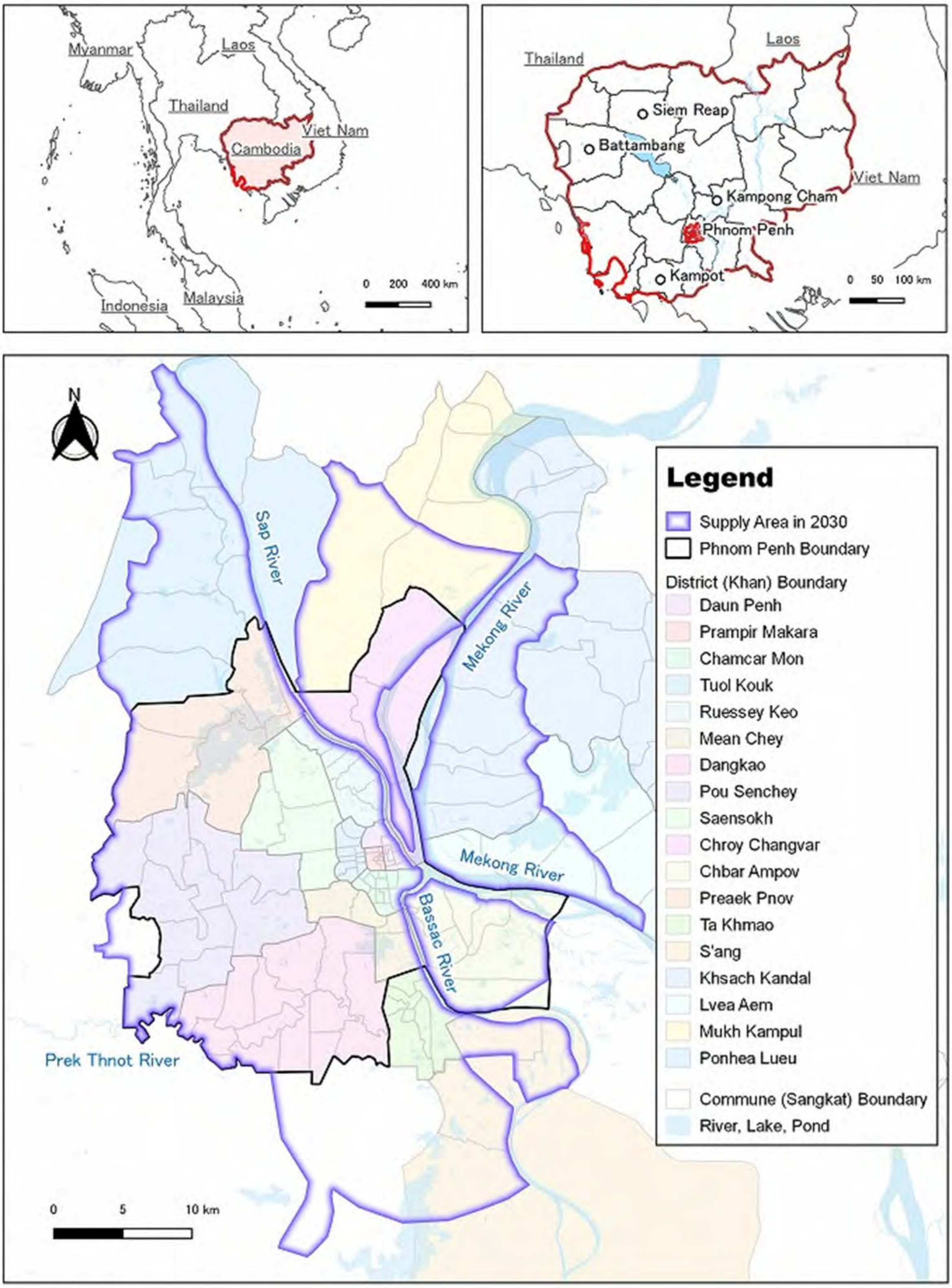


Location Map

ABBREVIATIONS

Abbreviation	Definition
ADB	Asian Development Bank
AfD	Agence Française de Développement (French Development Agency)
AIMF	Association Internationale des Maires Francophones
AMR	Automated Meter Reading
AMSL	Above Mean Sea Level
ASEAN	Association of South‐East Asian Nations
BAU	Bureau of Urban Affairs
BCP	Business Continuity Plan
CAPEX	Capital Expenditure
CDB	Commune data base
CDS	City Development Strategy
CMMS	Computerized Maintenance Management Software
CNMC	Cambodia National Mekong Committee
COVID-19	Coronavirus disease 2019
CSES	Cambodia Socio-Economic Survey
DMA	District Metered Area
EIA	Environmental Impact Assessment
EIB	European Investment Bank
EMP	Environmental Management Plan
EPC	Environmental Protection Contract
EU	European Union
FIDIC	International Federation of Consulting Engineers
FIRR	Financial Internal Rate of Return
F/S	Feasible Study
GDP	Gross Domestic Product Per Capita
GIS	Geographic Information System
GOJ	Government of Japan
GPCC	General Population Census of Cambodia
HDPE	High Density Polyethylene Pipe
HR	Human Resource
IEIA	Initial Environmental Impact Assessment
IMF	International Monetary Fund
ISO	International Organization for Standardization
IWA	International Water Association
IT	Information Technology
ITC	INSTITUTE of TECHNOLOGY of CAMBODIA
JICA	Japan International Cooperation Agency
KIS	Knowledge Information System
KPI	Key Performance Indicators
LDC	Least Developed Country
LIMS	Laboratory Information Management System
MEF	Ministry of Economy and Finance
MISTI	Ministry of Industry, Science, Technology, and Innovation
MOWRAM	Ministry of Water Resources and Meteorology
MPWT	Ministry of Public Works and Transport
MRC	Cambodia National Mekong Committee
MRD	Ministry of Rural Development
NDWQS	National Drinking Water Quality Standards
NIS	National Institute of Statistics Ministry of Planning
NR	National Road
NSDP	National Strategic Development Plan
O&M	Operation & Maintenance
ODA	Official Development Assistance
OJT	On-the-Job Training
OPEX	Operating Expenditure

PFI	Private Finance Initiative
PDCA	Plan-Do-Check-Act Cycle
PI	Performance Indicator
PPP	Public-Private Partnership
PPUTMP	Phnom Penh Urban Transportation Master Plan
PPWSA	Phnom Penh Water Supply Authority
PSP	Private Sector Participation
RGC	Royal Government of Cambodia
RR	Ring Road
SCADA	Supervisory Control And Data Acquisition
SDGs	Sustainable Development Goals
SOP	Standard Operating Procedures
SPC	Special Purpose Company
VAT	Value Added Tax
VGF	Viability Gap Funding
VSD	Variable Speed Drive
WHO	World Health Organization
WTO	World Trade Organization
WTP	Water Treatment Plant

UNITS OF MEASUREMENT

ABBREVIATION	DEFINITION
%	percentage
am	time between midnight and noon
℃	degree Celsius
cfu/ml	colony forming unit
cm	centimeter
cm^2	square centimeter
cusecs	cubic feet per second
dbt/d	dry basis ton per day
dl	deciliter
ha	hectare
hp	horsepower
in	inch
kg/d	kilogram per day
kg/m/h	kilogram per meter per hour
$kg/m^3/d$	kilogram per cubic meter per day
km	kilometer
km^2	square kilometer
kVA	kilovolt ampere
kW	kilowatt
kWh	kilowatt hour
l	liter
lpcd	liter per capita per day
m	meter
m/ha	meter per hectare
m/s	meter per second
m^2	square meter
m^3	cubic meter
m^3/d	cubic meter per day
m^3/h	cubic meter per hour
m^3/m	cubic meter per minute
$m^3/m^2/d$	cubic meter per square meter per day
m^3/s	cubic meter per second
m^3/y	cubic meter per year
MAF	million acre feet
MCM	million cubic meter
mg	million gallon
mg/l	milligram per liter
mgd	million gallon per day
ml	milliliter
mm	millimeter
Mm^3	million cubic meter
MMBTU	million British thermal unit
mph	miles per hour
MPN	most probable number
MW	megawatt
MWh	Megawatt hour
N/cm^2	newton per square centimeter
NTU	nephelometric turbidity unit
pm	time between 12 noon and 12 midnight
ppm	parts per million
TCU	true colour unit
wbt/d	wet basis ton per day
yd^2	square yard
µg/l	microgram per liter
µS/cm	micro-Siemens per centimeter

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND OF THE SURVEY

To develop the water supply sector, the Royal Government of Cambodia (hereinafter referred to as "RGC") launched the "National Policy on Water Supply and Sanitation" in February 2003. The Policy aims to "promote the people's quality of daily living and welfare" by providing "sufficient water supply and sanitation services with low costs [while] using a sustainable, and environmentally friendly sanitation system." Furthermore, under the "National Strategic Development Plan (NSDP)", the RGC is working to provide safe water to 80% of the urban population by 2015 and to 100% by 2025.

After the civil war, a series of development projects in the water supply sector were implemented in Phnom Penh by the Government of Japan (hereinafter referred to as "GOJ") and other donors. The projects included construction and improvement of water treatment plants (hereinafter referred to as "WTP"s) and water transmission / distribution systems, and technical assistance for operation and maintenance of facilities based on the "Phnom Penh Water Supply Development Plan" prepared under Japan International Cooperation Agency (hereinafter referred to as "JICA") assistance in 1993. With the successful completion of these projects, Phnom Penh city has achieved 24-hour water supply and water supply service ratio of more than 90%.

Phnom Penh Water Supply Authority (hereinafter referred to as "PPWSA"), which is in charge of the water supply operations in Phnom Penh, is currently expanding its water supply capacity by constructing new WTPs in accordance with the Third Water Supply Master Plan (2016-2030) (hereinafter referred to as the "Third Master Plan (M/P 2017)"), which was formulated with the assistance of the Government of France. However, due to the significant growth of population and commercial facilities, current water demand exceeds the water demand projected in the Third Master Plan (M/P 2017).

In some distribution areas, water demand has intensified significantly due to construction of new buildings, large-scale commercial facilities, etc. and distribution water pressure frequently decreases during morning and evening peak hours due to high water consumption.

In response to insufficient water pressure, users have taken measures such as installing pumps in each building and suctioning from the distribution pipes. This causes negative pressure inside the distribution pipes and increases the risk of water quality deterioration.

In addition, there are several areas in the PPWSA water supply area that are not covered by the Third Master Plan (M/P 2017). It is necessary to collect and examine further information and update the Third Master Plan (M/P 2017) in order to consider future water supply development activities.

1.2 OBJECTIVE AND SCOPE OF THE SURVEY

The objective of this data collection survey (hereinafter referred to as "the Survey") is to:

- address the water shortage issues in Phnom Penh and its suburbs within the PPWSA service area,
- review the water demand projection up to the target year of the Third Master Plan (M/P 2017), and
- formulate the direction of future water supply development by collecting and examining information based on the updated water demand projection and city development plans.

1.2.1 Objective and Scope of the Survey

The objective and scope of the survey are as shown in ***Table 1.2.1***. Contents of the survey are shown in ***Table 1.2.2***.

Table 1.2.1 Objective and Scope of the Survey

Objective	Due to the recent increase in population and commercial facilities in Phnom Penh, discrepancies between the water demand projection of the Third Master Plan (M/P 2017) and the actual demand have been observed. Moreover, future city development plans were not taken into consideration in that Master Plan. In response to these issues, the objective of this survey is to collect and examine further information and formulate the direction of water supply development in Phnom Penh.
Scope of the Survey	In order to achieve the above objective, a survey of the contents shown in Table 1.2.2 will be conducted. A report for an updated water supply master plan targeted for the 2030 will be prepared and submitted to JICA and PPWSA after the explanation and consultation sessions.

Source: JICA Data Collection Survey Team

Table 1.2.2 Contents of the Survey

- Literature survey
- Discussion on Inception Report with PPWSA
- Existing condition survey and data collection
- Confirmation of target year and the planned service area of PPWSA
- Survey for potential new water intake and water quality analysis
- Definition of issues on management of water supply services by PPWSA
- Discussion on Interim Report with PPWSA
- Water resources development planning and intake facility planning
- Planning for development of water treatment plants
- Water transmission and distribution system conceptual planning and hydraulic analysis
- Staged development planning for water supply system in Phnom Penh
- Human resources development planning
- Institutional improvement planning
- Financial Analysis
- Discussion on Draft Final Report with PPWSA
- Submission of Final Report and presentation on Final Report with PPWSA

Source: JICA Data Collection Survey Team

1.2.2 Related Agencies of the Survey

Related Agencies are as follows:

Table 1.2.3 Related Agencies of the Survey

Implementing Agency	Phnom Penh Water Supply Authority (PPWSA)
Executing Agency	Phnom Penh Water Supply Authority (PPWSA)

Source: JICA Data Collection Survey Team

1.2.3 Main Content of This Interim Report

The results of this survey will be summarized in this report as follows.

Chapter 1 Introduction
Chapter 2 Condition in Phnom Penh City / Related Plans and Policies
Chapter 3 Review of the Third Master plan
Chapter 4 Water Demand Projection
Chapter 5 Water Resources
Chapter 6 Water Production Facilities
Chapter 7 Transmission and Distribution Network
Chapter 8 Proposed Implementation Plan
Chapter 9 Institutional Development
Chapter 10 Human Resources Development
Chapter 11 Project Cost
Chapter 12 Financial Study

1.3 TARGET YEAR AND SURVEY AREA

1.3.1 Target Year

Water demand for the year 2030 is forecast in this survey. The target year of the water demand forecast in the Third Master Plan (M/P 2017) was the year 2030. Since the major objective of the current survey is to re-evaluate the Third Master Plan (M/P 2017) based on current conditions, the target year of the water demand forecast for this survey is also set to the year 2030.

1.3.2 Supply Area

The target area of the Survey is shown in ***Figure 1.3.1***. The service area of PPWSA is Phnom Penh Capital City and Ta Khmao City, Kandal Province, which neighbours Phnom Penh to the south and large-scale development areas. Details are available in ***Chapter 4***. In the figure below, the ID number (No.) and the year of inclusion in the water supply area are shown for each large-scale development area and the surroundings. The color coding of the water supply area shows the coverage area of the water supply area by that year. The color coding of the large development areas is based on the year in which most of the groups are included.

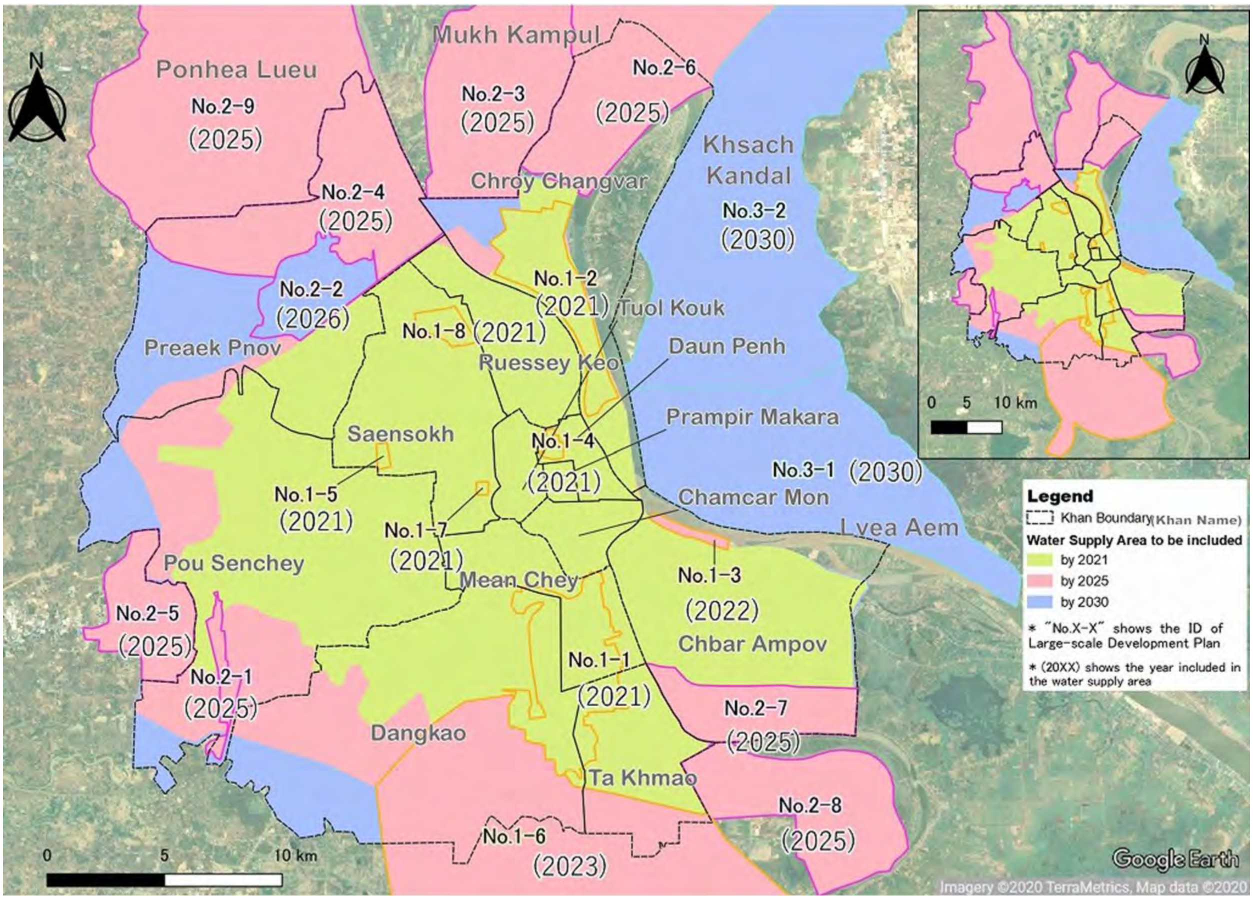


Figure 1.3.1 Supply Area

Source: JICA Data Collection Survey Team

Table 1.3.1 Large-Scale Development Projects and Surrounding Areas to be Included in the Water Supply Area

No	Name	Target Supply Year
1-1	ING City	2021
1-2	OCIC & Okide Villa	2021
1-3	Kos Norea Project	2022
1-4	Boeng Kak	2021
1-5	Okide Villa	2021
1-6	New Phnom Penh Airport City	2023
1-7	Booyoung Town	2021

No	Name	Target Supply Year
1-8	Grand Phnom Penh international City	2021
2-1	Special Economic Zone (SEZ)	2025
2-2	Ta Mouk Lake	2026
2-3	private utilities	2025
2-4	Prek Pnov (private)	2025
2-5	Bek Chan (private)	2025
2-6	North of Chroy Changvar	2025
2-7	private utilities	2025
2-8	private utilities	2025
2-9	Preaek Ta Teaen, Vihear Luong, Ponhea Lueu, Phsar Daek, Kampong Luong, Chhveang, Phnum Bat, Chrey Loas	2025
3-1	Arey Khsat & Leva Aem commune (private)	2030
3-2	Preaek Luong, Preaek Takov, Svay Chrum, Preaek Ta Mak, Preaek Ampil, Puk Russei	2030

Source: JICA Data Collection Survey Team

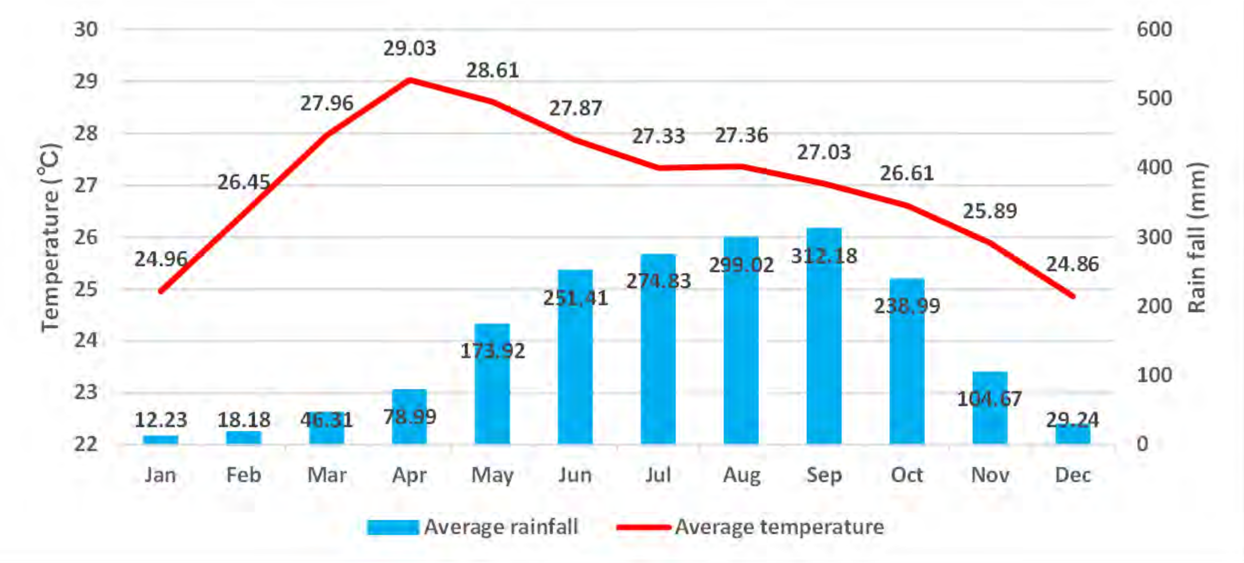
CHAPTER 2 CONDITIONS IN PHNOM PENH CITY / RELATED PLANS AND POLICIES

2.1 CONDITIONS IN PHNOM PENH CITY

2.1.1 Physical Conditions

(1) Meteorological Phenomenon

Cambodia's climate is characterized by tropical monsoons common to Southeast Asia. The wet season lasts from June to December and the dry season from January to May. During the wet season, southwesterly winds carry moist air to the area and provide 80% to 90% of the yearly rainfall. Temperatures are homogeneous throughout the country. Highest temperatures are experienced in February through March, with temperatures reaching 35 degrees Celsius to 40 degrees Celsius. Average national rainfalls and temperatures are shown in ***Figure 2.1.1*** below.



*Average value from 1901 to 2016

Figure 2.1.1 Monthly Average Temperature and Rainfall

Source: World Bank, Climate Change Knowledge Portal

(2) Topography

Cambodia has a land area[1] of 181,035 km². Most of Cambodia is covered by low-lying plains, with mountain ranges in the north-east and northern regions of the country. The north-east and northern regions border Vietnam and Lao PDR and are characterized by deep forests that are rich in resources and biodiversity.

The waterways of Phnom Penh are shown in ***Figure 2.1.2***. The Mekong River, an international waterway, runs through the city from the north. Tonle Sap Lake is located to the north in the central plains. The Mekong River splits into the Bassac River, and the Bassac River merges with the Prek Thnot River to the south of Phnom Penh. To the north of Phnom Penh is Lake Tamok, and Lake Cheung Aek to the south. Filling-in of lakes and marshes has increased in recent years due to urbanization. Details of waterways in the area can be found in ***Chapter 5***.

[1] National Institute of Statistics Ministry of Planning: General Population Census of the Kingdom of Cambodia 2019 National Report on Final Census Results

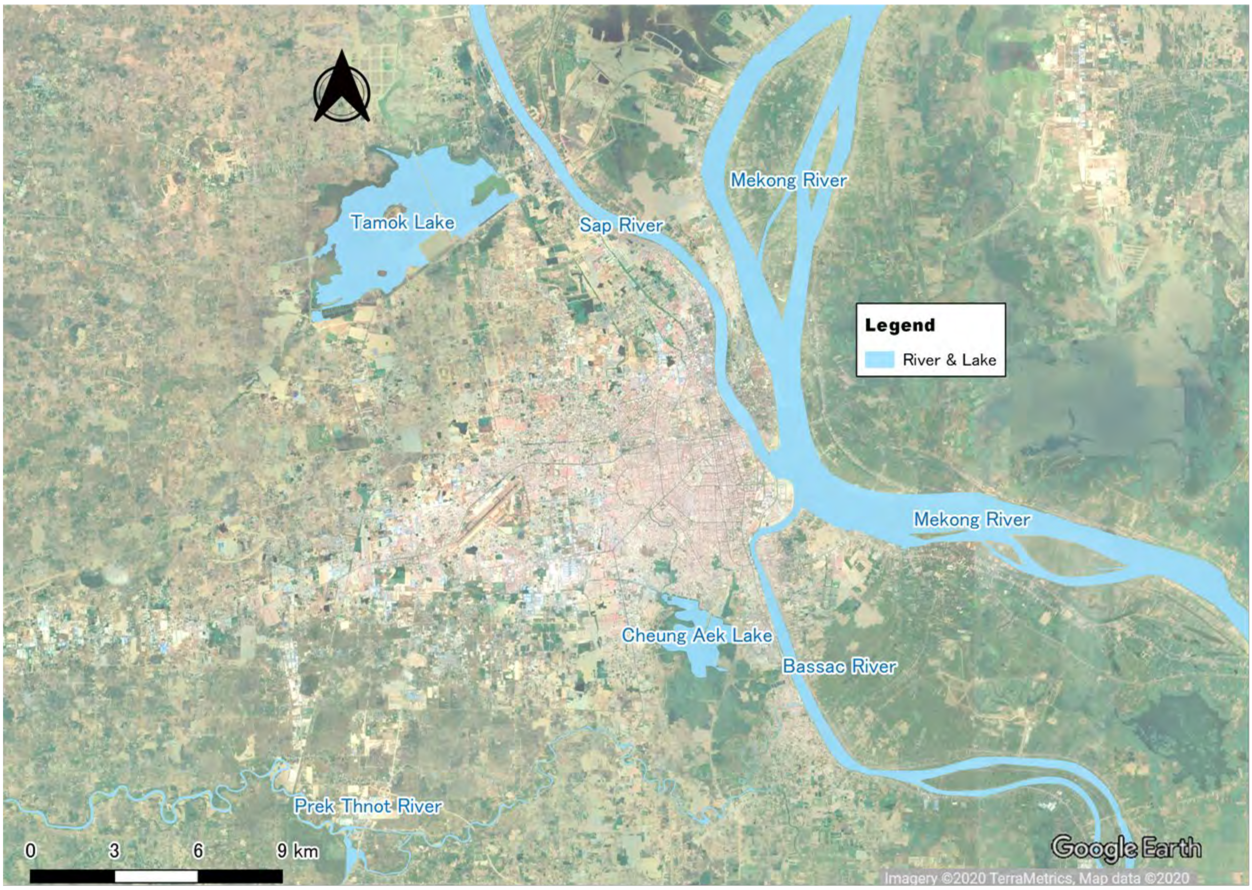


Figure 2.1.2 Rivers around the Capital Phnom Penh
Source: JICA Data Collection Survey Team

Phnom Penh is relatively flat, with an elevation of +10 to +15 m AMSL[2]. Some areas of the city are below the high-water level of the Mekong River, and the city center and surrounding areas are archetypical flood plains. Elevations of the city and its surrounding lands are shown in ***Figure 2.1.3***.

[2] meters above mean sea level (hereinafter referred to as m AMSL)

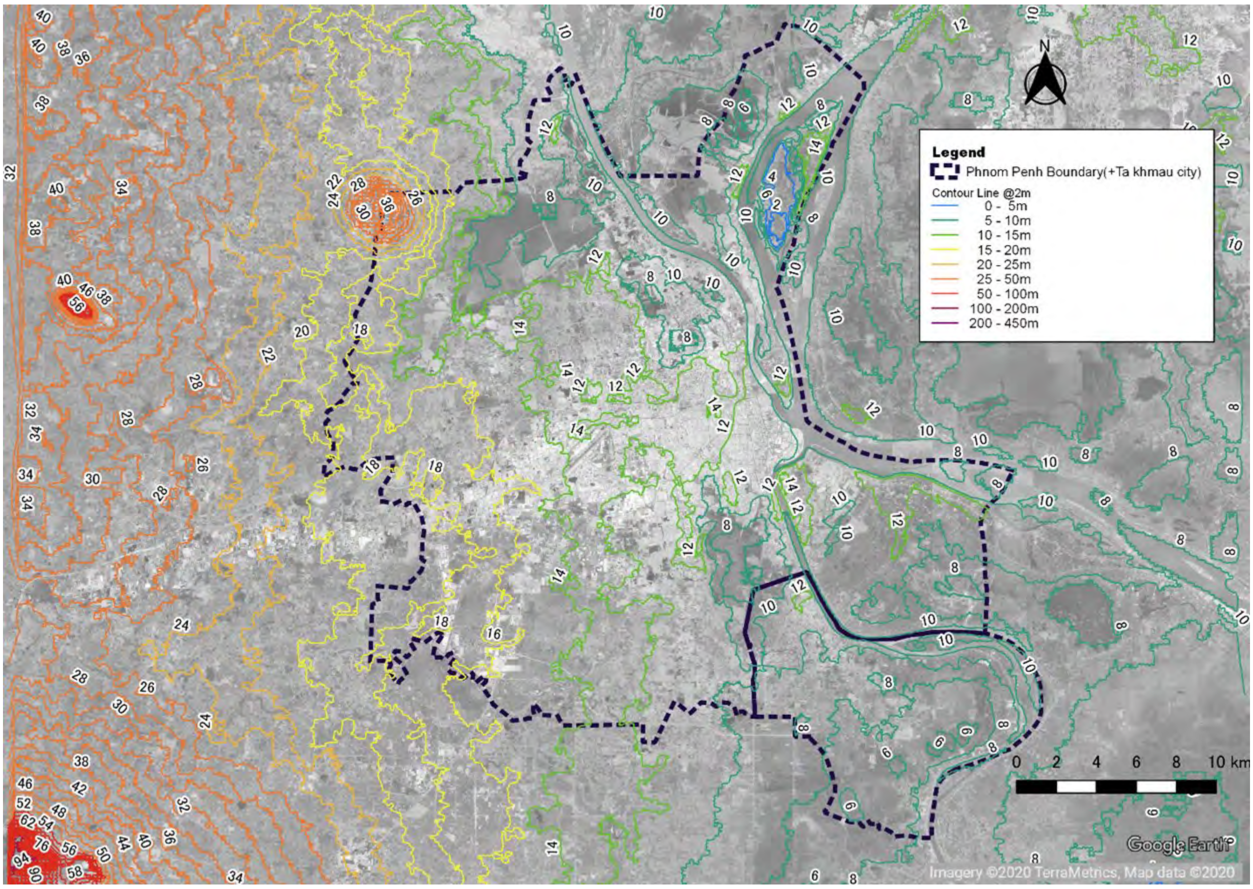


Figure 2.1.3 Elevation Map of Phnom Penh Capital City and Kandal Province

Source: JICA Data Collection Survey Team based on the topographic survey data (Khan Daun Penh, 7 Makara, Chamcar Mon) provide by PPWSA and topographical data from GPS Visualizer

(3) Geography

In terms of geological conditions of Cambodia, almost all of the land is situated on relatively new ground, such as quaternary sedimentary rocks and unconsolidated sediments. Relatively old soil, such as the upper Jurassic-cretaceous sedimentary unit, exists in the northeast area. Lower-middle Jurassic sedimentary units are situated in the southwest part of Cambodia. Phnom Penh is mainly located on quaternary sedimentary rocks.

Geologic structure of the Mekong Delta region, where the Study Area is situated, was formed in the Precambrian to Holocene ages. Old Alluvium was formed in a deltaic shape between the Pliocene and Pleistocene by the Mekong and its tributaries and then the Holocene deltaic alluvium was formed. The Holocene Alluvium, mainly consisting of unconsolidated silt and clay with some lenses of sand virtually blankets the entire delta. The Holocene Alluvium in and around the Study Area generally has a thickness of less than 25 m. The Holocene Alluvium differs from the Old Alluvium in having a generally finer texture, almost no laterite, and a relative abundance of shell and lignite layers. The surface geological condition of Phnom Penh city is characterised by the sandy mud covered on base terrane inclined from west to east, as well as soft clay layer at some places.

2.1.2 Social Conditions

(1) Population

The last census performed in Cambodia was the General Population Census of Cambodia 2019 (hereinafter referred to as "GPCC"). Population trends in Cambodia are shown in ***Figure 2.1.4***.

According to the census, the population in Cambodia in 2019 was 15.6 million people.

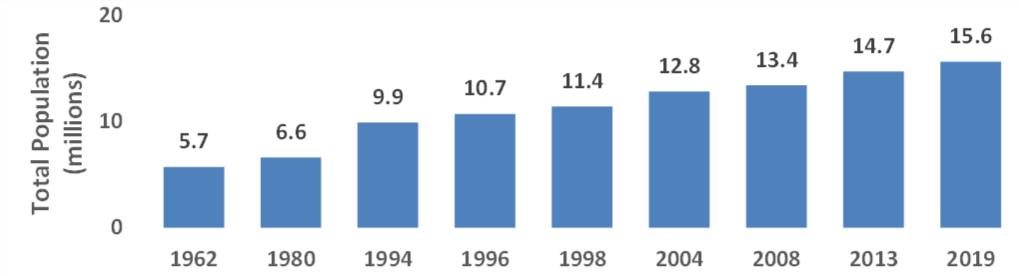
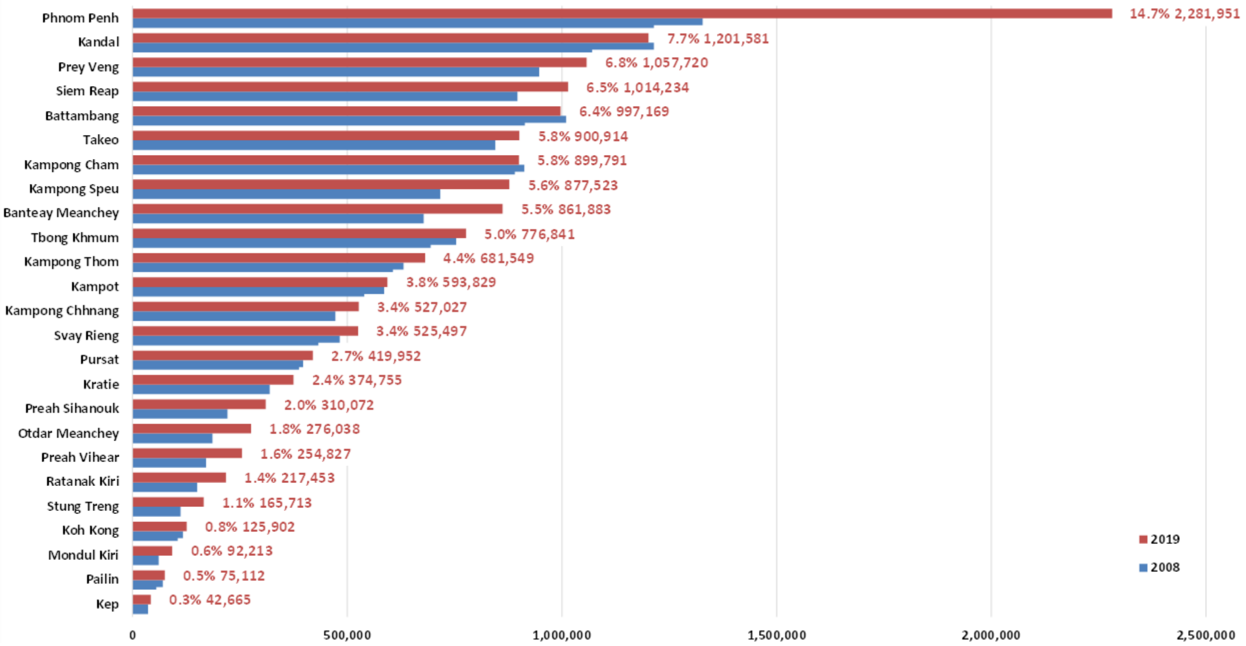


Figure 2.1.4 Population in Cambodia

Source: General Population Census of the Kingdom of Cambodia 2019 National Report on Final Census Results by National Institute of Statistics Ministry of Planning

The 2019 populations of major cities are shown in ***Figure 2.1.5***. The population of Phnom Penh was 2,281,951, accounting for 14.7% of the national population. Population density was 3,361 people per km^2. When compared to the census results of 2008 (population of 1,327,615 accounting for 9.9% of the national population), concentration of the national population in the Phnom Penh capital over the last 10 years is evident.



* The population show the results of the 2019 survey.

Figure 2.1.5 Population of Each City in 2019

Source: General Population Census of the Kingdom of Cambodia 2019 National Report on Final Census Results by National Institute of Statistics Ministry of Planning

The next most populous region was Kandal Province with 1,201,581 people, accounting for 7.7% of the total national population. Ta Khmao city, which neighbors Phnom Penh, had a population of 75,629[3].

Further details of demographics within Phnom Penh are given in ***Chapter 4***.

[3] National Institute of Statistics Ministry of Planning: General Population Census of the Kingdom of Cambodia 2019 National Report on Final Census Results

(2) Administrative Structure

The administrative structure of Cambodia is shown in ***Figure 2.1.6***. Based on the Law on Administrative Management of the Capital, Provinces, Municipalities, Districts and Khans of 2008, Cambodia is made up of Phnom Penh municipality and 24 cities.

Phnom Penh municipality is divided into sections (hereinafter referred to as "Khan"), which are subdivided into quarters (hereinafter referred to as "Sangkat"). Provinces are divided into cities and Sroks. Cities are made up of Sangkats, and Sroks are made up of Khums.

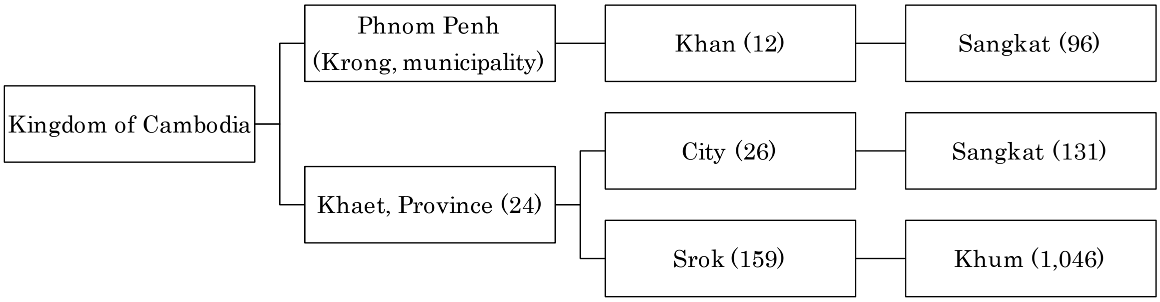


Figure 2.1.6 Administrative Structure of Cambodia

*The number in parentheses represents the number of administrative divisions.

Source: JICA Data Collection Survey Team based on The Project for Capacity Development for Implementing the Organic Law at Capital & Provincial Level, Kingdom of Cambodia

A history of these administrative units is summarized in ***Table 2.1.1***.

Table 2.1.1 History of Administrative Units of Phnom Penh Capital City

YEAR	CONTENTS
2010	Khan Russei Keo was split to create Khan Sen Sok
2011	Khan Dangkao was split to create Khan Por Sen Chey
2012	Twenty (20) communes of the Kandal province were integrated into Phnom Penh Municipality, representing an additional 304 km^2 and a population of 170,000
2013	Three (3) new Khans were created: Khan Mean Chey was split to create Khan Chbar Ampov Khans Sen Sok and Por Sen Chey were split to create Khan Prek Pnov Khan Russei Keo was split to create Khan Chroy Changvar
2018	Khan Chamkar Mon was split to create Khan Chamkar Mon and Khan Boeng Kengkang Khan Boeng Kengkang was established by the sub-decree issued on 8 Jan 2019. It is comprised of 7 Sangkat of Khan Chamkar Mon: 1- Boeng Kengkang Ti Muoy, 2- Boeng Kengkang Ti Pir, 3- Boeng Kengkang Ti Bei, 4- Olympic, 5- Tumnob Tuek, 6- Tuol Svay Prey Ti Muoy, 7- Tuol Svay Prey Ti Pir Khan Pour Saenchey was split to create Khan Pour Saenchey and Khan Kambol and Khan Dangkao was split to create Khan Dangkao and Khan Kambol Khan Kambol which was established by the sub-decree issued on 8 Jan 2019, is comprised of 6 Sangkat from Khan Pur Senchey and 1 Sangkat from Khan Dangkao; 1- Kamboul, 2- Kantouk, 3- Ovlaok, 4- Snaor, 5- Phleung Chheh Roteh, 6- Boeng Thum, 7- Prateah Lang (from Dangkao Khan)
2019	Four (4) sangkat were included in Ta Khumao city (Svay Rolum, Kaoh Anlong Chen, Setbou, and Roka Khpuos)
	After the completion of the Chroy Chongva-Akreiy Ksatr Bridge, a part of the Lvea Aem district of Kandal Province is planned to be integrated into the Phnom Penh Capital City.

Source: JICA Data Collection Survey Team based on the Third Water Supply Master Plan (2016-2030), (Revised in 2017)

The central area of Phnom Penh was redistricted in 2018; however, billing and O&M operations of PPWSA were managed according to the pre-2018 district arrangement. This survey will re-evaluate the PPWSA administrative districts. Administrative districts of PPWSA are shown in ***Figure 2.1.7***.

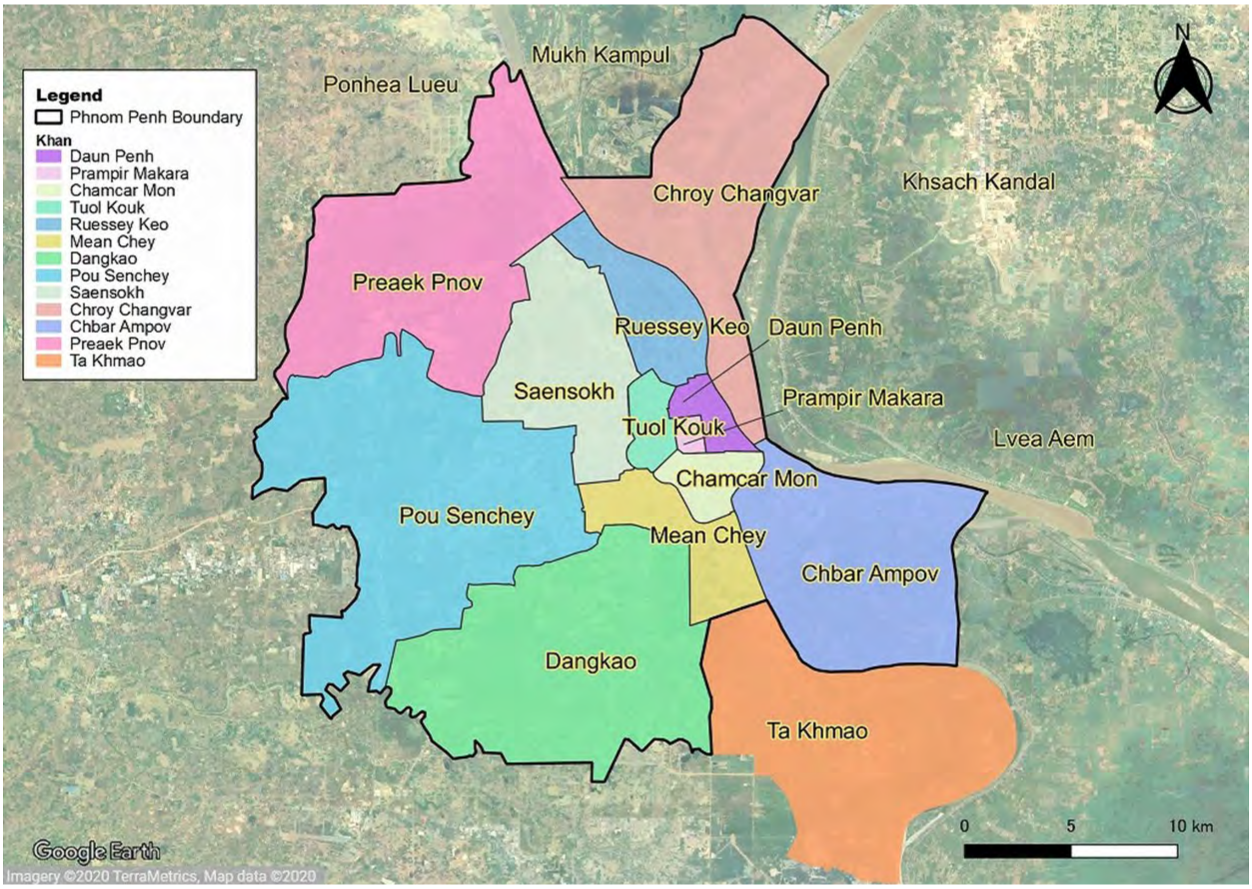


Figure 2.1.7 Administrative Areas of Phnom Penh Capital and Ta Kumao City
Source: JICA Data Collection Survey Team based on PPWSA

2.1.3 Economic Conditions

The per capita gross domestic product (hereinafter referred to as "GDP") of Cambodia is approximately 1,607 USD[4]. This is lower than the per capita GDP of neighboring countries and in Asia in general.

Cambodia is included in the list of least developed countries (hereinafter referred to as "LDC").

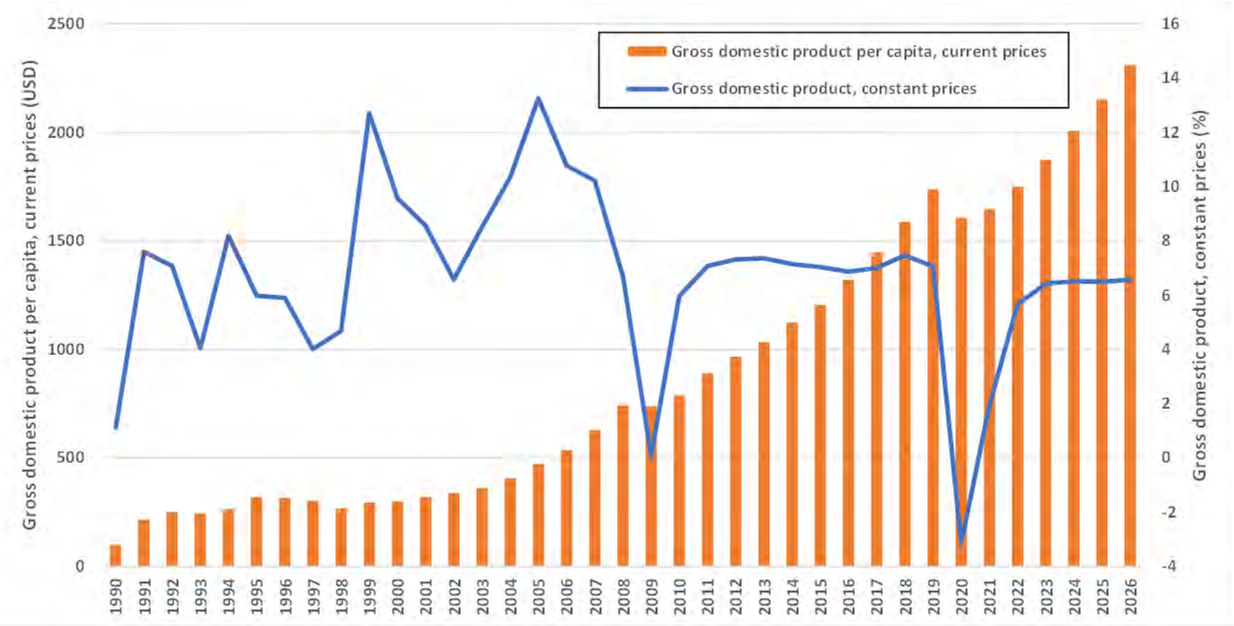
Table 2.1.2 Comparison of Per Capita GDP of Nearby Countries

Country	Cambodia	China	Hong Kong	India	Indonesia	Japan	Lao P.D.R.
Gross domestic product per capita, current prices (USD)	1,607	10,511	46,657	1,930	3,922	40,089	2,587
Country	**Malaysia**	**Myanmar**	**Philippines**	**Singapore**	**Taiwan**	**Thailand**	**Vietnam**
Gross domestic product per capita, current prices (USD)	10,231	1,527	3,323	59,795	28,358	7,188	3,523

Source: JICA Data Collection Survey Team based on International Monetary Fund, World Economic Outlook Database, October 2021

Per capital GDP trends in Cambodia are shown in ***Figure 2.1.8***.

[4] International Monetary Fund, World Economic Outlook Database, October 2020



*Predicted value after 2018

Figure 2.1.8 Changes in Nominal GDP Per Capita and Real GDP Growth Rate

Source: JICA Data Collection Survey Team based on International Monetary Fund, World Economic Outlook Database, October 2021

Thanks to the stable political situation in recent years, GDP grew at over 10% for four straight years from 2004 to 2007. Due to sharp increases in food and oil prices in 2008, and the global financial crisis in 2009, GDP growth fell to 0.1% in 2009, but recovered to 6.0% by 2010. Since 2011, the economy has been growing at a steady 7.0% per year. The International Monetary Fund (hereinafter referred to as the "IMF"), predicts slowing of the economy in 2020 due the impacts of the Coronavirus pandemic, but expects the economy to recover and continue 6~7% growth into the foreseeable future.

In addition, since the end of the civil war in 1990, Cambodia has joined several international trade agreements, such as ASEAN in 1999 and WTO in 2004, thereby strengthening its economic presence in the region and in the world.

Ratio of GDP by industry is shown in ***Figure 2.1.9***. In 2019, agriculture accounted for 22.9%, industry for 37.8%, and services for 39.4% of GDP[5]. Compared 2010, the percentage of agriculture has fallen by almost one half. The construction industry has grown significantly due to demand for infrastructure and urbanization of the country. This trend is expected to continue in the future.

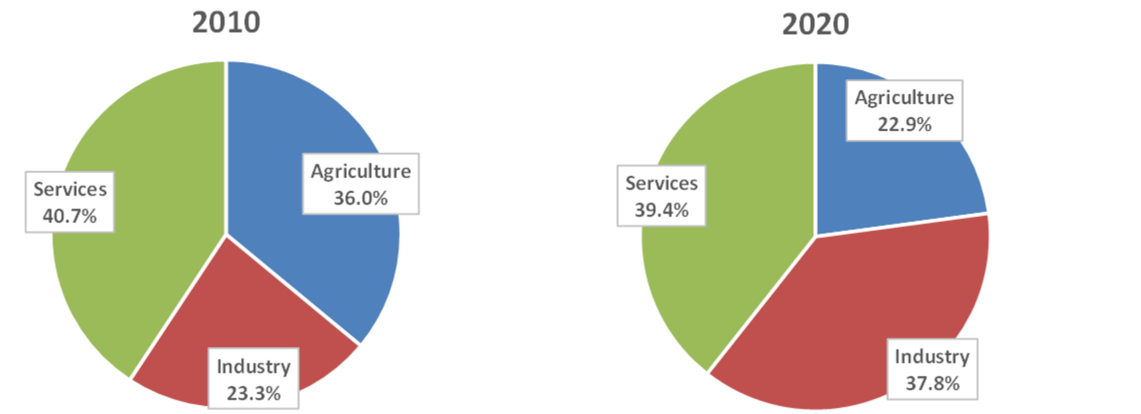


Figure 2.1.9 Ratio of GDP by Industry

Source: Asian Development Bank (ADB): Key Indicators for Asia and the Pacific 2021

The Cambodia Socio-Economic Survey (hereinafter referred to as the "CSES") was conducted between 2013 and 2017. Household monthly income resulting from the survey is shown in ***Table 2.1.3***.

[5] Asian Development Bank (ADB) : Key Indicators for Asia and the Pacific 2020

Table 2.1.3 Average Household Incomes in Camodia

INCOME PER MONTH (THOUSAND RIEL)	2013	2014	2015	2016	2017
Cambodia	1,236	1,434	1,619	1,777	1,960
Phnom Penh	2,517	2,856	2,938	2,907	2,853
Other urban	2,112	1,872	2,250	2,461	2,498
Other rural	931	1,163	1,329	1,517	1,760

Source: Cambodia Socio-Economic Survey(CSES)2017

Household monthly incomes have been increasing month by month, and the gap between urban and rural incomes has been decreasing year by year, although a 1.6-fold disparity remains as of 2017.

In 2004, over 50% of the population lived in poverty. By 2018, that number was reduced to 12%[6]. However, poverty reduction remains an important issue in Cambodia. Comprehensive growth founded on diversification of industry and improvement of productivity will be important for continued poverty reduction in the country.

[6] Asian Development Bank (ADB) : Poverty Data Cambodia

2.2 RELATED PLANS AND POLICIES

2.2.1 Development plan

(1) National Policy, Development Goals, Plans

1) Rectangular Strategy Phase IV

The Rectangular Strategy Phase IV was introduced on July 16th, 2004 by Prime Minister Hun Sen during the first cabinet meeting after the establishment of the Third Administration. The Strategy comprises of 1) strengthening of agriculture, 2) restoration and construction of infrastructure, 3) private sector and job development, and 4) human resource development. At its center is "Acceleration of Governance Reform" which promotes good governance by prioritizing corruption eradication, legal and judicial reforms, administrative and financial reforms, and military reforms.

2) National Strategic Development Plan (NSDP)

The National Strategic Development Plan (hereinafter referred to as "NSDP") is the national policy to put the Rectangular Strategy in action. In the water sector, the plan aims to provide access to clean water to 85% of the urban population by 2018, and to 100% of the urban population by 2025. It also prioritizes the following items related to the water sector:

- Strengthening water supply regulations (water supply law, etc.)
- Promoting decentralization of water services through economic and technical regulations of the central government
- Independence of rural water works as state-owned enterprises (public corporations)
- Increasing financing (formulation of development plan and business plan, utilization of the private sector, implementation of the "Water for All" program, etc.)
- Improving operational performance and access to water (renewal of existing facilities, identification and resolution of issues, human resources development, establishment of water supply association, effective utilization of PPWSA, optimization of water quality management system, etc.)
- Conserving water resources.

(2) City Development Plan

1) Land Use Plan

Phnom Penh Capital formulated its City Development Strategy (hereinafter referred to as "CDS") for the target year 2015 based on the NSDP in 2005. In order to develop Phnom Penh and to improve civic life, CDS has listed the following five key visions: (1) Land use and housing; (2) Environment and natural resources; (3) Infrastructure and transportation; (4) Social services; and (5) Economic development.

As the urban development Master Plan of Phnom Penh City Center (hereinafter referred to as "PPCC"), the "White Book on Development and Planning of Phnom Penh" was issued in October 2007 (hereinafter referred to as "White Book"). In the White Book, the land use plan for the target year 2035 was formulated based on land use in 2004. The land use plan was approved in the committee for land management and urban planning for the capital, which was established in accordance with a Royal Decree, and finally approved with the issuance of sub-decree dated on 23rd December 2016. As for actual land use of Phnom Penh, lake and swamp areas decreased almost by half due to urbanization and industrialization in the city.

2) Phnom Penh City Development Plan

Major development projects planned or underway in Phnom Penh and Ta Khmao since the Third Master Plan (2017) are shown in ***Figure 2.2.1*** and ***Table 2.2.1***.

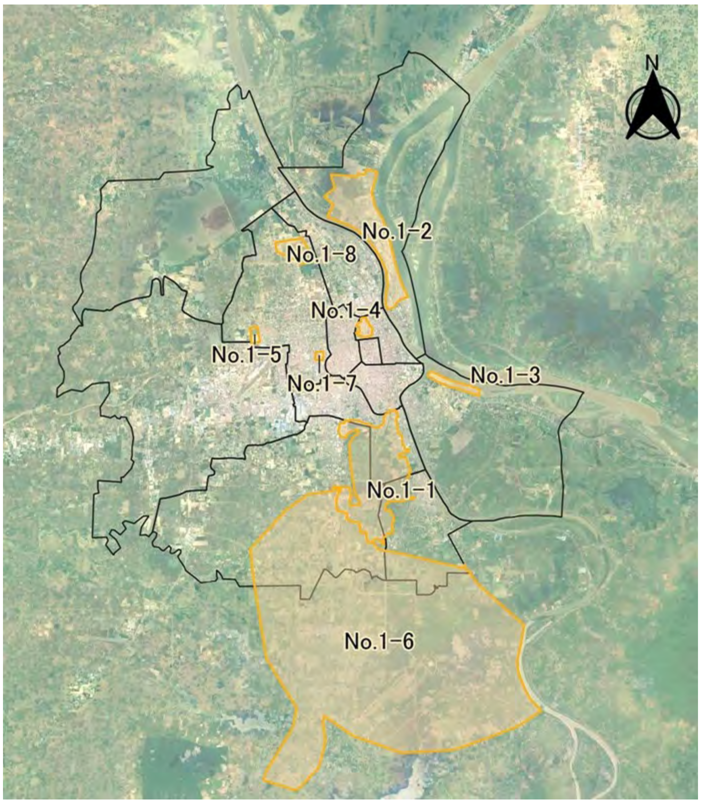


Figure 2.2.1 Major Development Projects Planned or Underway in Phnom Penh and its Surroundings

Source: JICA Data Collection Survey Team based on PPWSA data

Table 2.2.1 Major Development Projects Planned or Underway in Phnom Penh and its Surroundings

NO	NAME	AREA	DESCRIPTION
1-1	ING City	2,572 ha	4 stages, 5 years/stage, 2 stages are assumed to be completed by 2030
1-2	OCIC & Okide Villa	1,300 ha	Condominium, residential area
1-3	Kos Norea Project	124 ha	30,000 m3/day according to Master Plan, backfilling will be finished in next 2 years, commercial, business, and high-rise residential buildings.
1-4	Boeng Kak	80 ha	Business area
1-5	Okide Villa	50 ha	Villa, few condominiums, business center, commercial area
1-6	New Phnom Penh Airport	2,600ha	New International Airport and New Airport City
1-7	Booyoung Town	27 ha	40 apartments and 7 complexes
1-8	Grand Phnom Penh International City	150 ha	Golf course and housing area

Source: JICA Data Collection Survey Team based on PPWSA data

2.2.2 Road Development Plans

The Phnom Penh Urban Transportation Master Plan (hereinafter referred to as "PPUTMP") was formulated as a comprehensive urban transportation plan for Phnom Penh with a target year of 2035. It includes plans to develop roads in the city.

The outline of the road development plan is shown in ***Figure 2-2.1***. PPUTMP includes plans to develop four ring roads from RR1 to RR4 and six radial roads from NR1 to NR6, extending from the center as major highways.

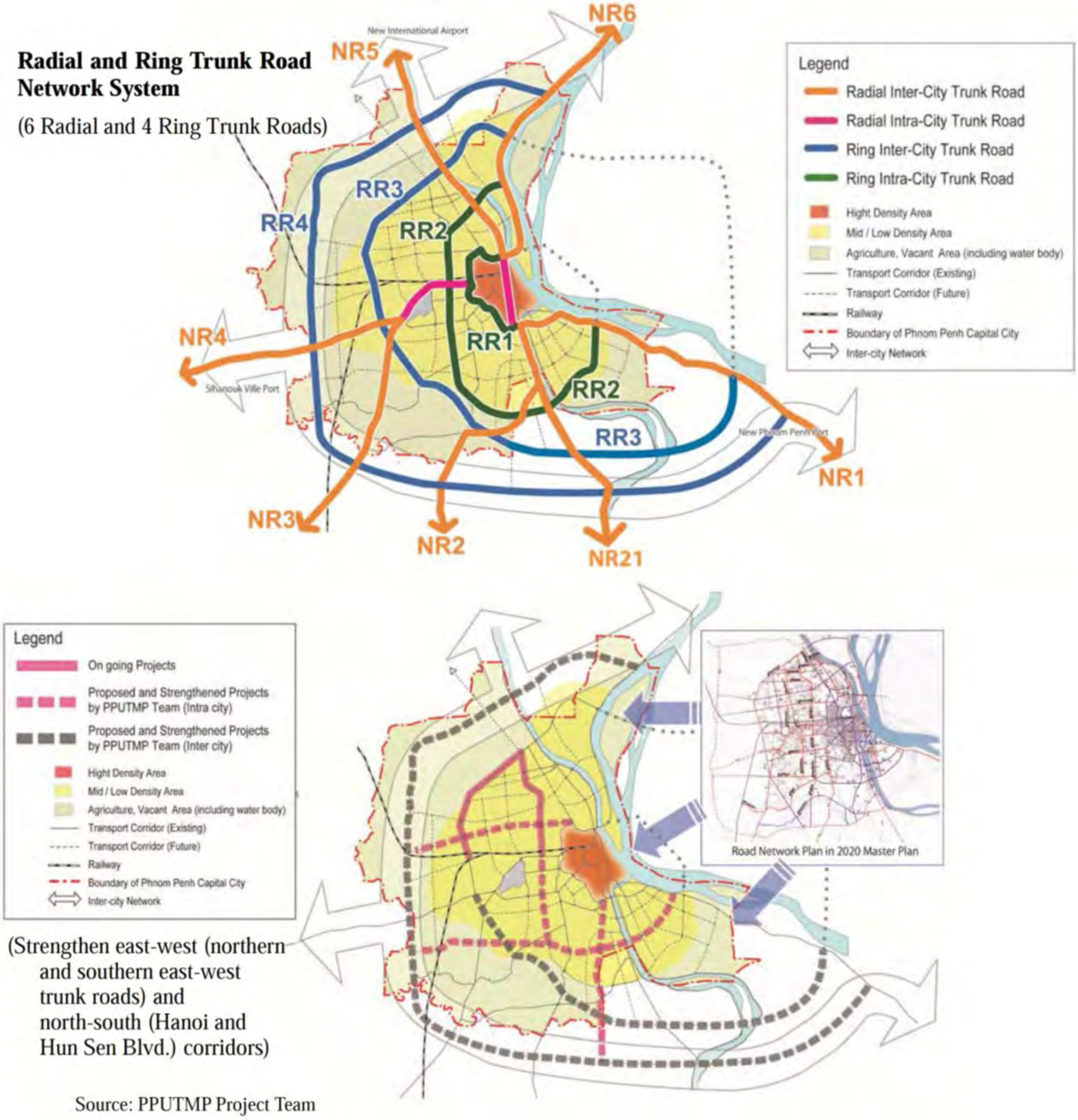


Figure 2.2.2 2035 Road Development Plan
Source: The Phnom Penh Urban Transportation Master Plan

The PPUTMP includes plans to improve the main highways and utilize public transportation on the main roads. This will have impacts on O&M of transmission and distribution mains.

Furthermore, the PPUTMP includes plans to build bridges across the Mekong River. One is the Changvar-Svay Chrum Bridge which will connect the center of the capital Phnom Penh with the Leva Aem district in Kandal Province. The planned bridge construction site is shown in ***Figure 2-2.1***. The construction of this bridge was listed as a priority project in South Korea's assistance project from 2019 to 2023. In addition, a feasibility study of the Areiy Ksatr-Kdey Takoy Bridge is currently underway.

After the construction of these bridges, the Svay Chrum and Areiy Ksatr currently in Kandal Province will come under the administration of the Phnom Penh Capital City. Resulting expansion of the metropolitan area and further development are expected.

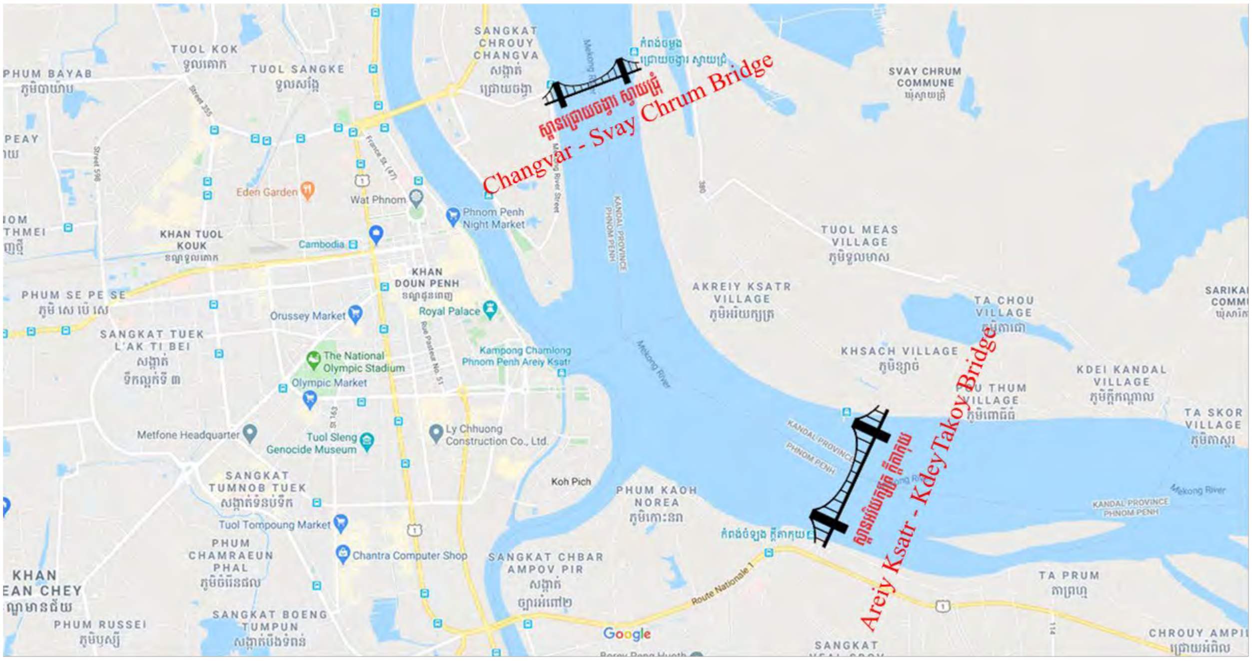


Figure 2.2.3 Planned Bridge Constructions
Source: The Cambodia Constructors Association

2.2.3 Laws and Regulations

(1) Laws and Regulations for Water Supply Sector

Cambodian laws and regulations pertaining to the water sector are shown in ***Table 2.2.2***

Table 2.2.2 Laws and Regulations for Water Supply Sector

ITEM	DESCRIPTION	YEAR	AUTHORITY
Law	Law on Water Resources Management of the Kingdom of Cambodia	2007	RGC
	Law on Water Supply and Sanitation Regulatory Law (draft)	2005	RGC
Sub-decree	Creation of Phnom Penh Autonomous Water Supply Authority	1996	RGC
	Sub-Decree on Build Operate Transfer Contract	1998	RGC
	Sub-Decree on Establishment of Siem Reap Water Authority as Public Economic Establishment	2007	RGC
	Sub-Decree on Water Licensing (draft)	2011	RGC
	Sub-Decree on Water Quality (draft)	2010	RGC
	Sub-Decree on the Organization and Functioning of MIH	2014	MIH
	Sub-Decree on the Organizing and Functioning of General Department of Portable Water Supply	2016	RGC
Prakas	Prakas on Procedure for Issuing, Revising, Suspending and Revoking Permit for Water Supply Business	2014	MIH
	Prakas on Establishment of Evaluation Committee for Issuing the Licensing the Water Operator	2014	MIH
	Prakas on the Organizing and Functioning of Department of Portable Water Supply	2014	MIH
	Prakas on National Drinking Water Quality Standards	2015	MIH
	Prakas on Providing Licenses for Operating in Water Supply	2015	MIH
	Prakas on Transferring Coverage Areas and Water Supply Production	2015	MIH
	Prakas on Determination of Depreciation Rate for Production Facilities and Distribution Network in Urban Water Supply Sector	2016	MIH
	Prakas on Procedure for Water Tariff Setting that the Water Supply Operators Have Right to Charge from Served Customers	2016	MIH
	Prakas on Benchmarking/Setting of Performance Indicator for Evaluation	2016	MIH
	Prakas on Providing Permanent Permit for Water Supply Operators	2016	MIH
	Prakas on Organizational and Functioning of Department of Information and Documentation	2017	MIH
	Prakas on Organizational and Functioning of Department of Planning and Data Management	2017	MIH
	Prakas on Organizational and Functioning of Department of Water Policy	2017	MIH
	Prakas on Organizational and Functioning of Department of Technical and Project Management	2017	MIH
	Prakas on Organizational and Functioning of Department of Water Regulation	2017	MIH
	MIME's Action Plan for Urban Water Supply Sector	2010	MIME
	Water and Sanitation Sector Financing Strategy for Cambodia	2010	MIME
	Rural Water Supply, Sanitation and Hygiene Strategy, 2011-2025	2011	MRD
	National Policy on Water Supply and Sanitation	2003	RGC
Policy/ Strategy	MoU between MIME and MRD on the water supply (pipe network)	2005	MIME /MRD
	National Strategic Development Plan 2014 -2018	2014	MIME
Standard	Drinking Water Quality Standards (DWS)	2004	MIME
	National Drinking Water Quality Standards (NDWQS)	2015	MIH

*RGC (Royal Government of Cambodia), MRD (Ministry of Rural Development), MISTI (Ministry of Industry, Science, Technology and Innovation) were renamed from MIME (Ministry of Industry, Mines and Energy), and MIH (Ministry of Industry and Handicraft)

Source: The project on strengthening administrative capacity of urban water supply in Cambodia

(2) Laws and Regulations Related to Water Resources Management

Laws and regulations relevant to water resources management and water intake are summarized in ***Table 2.2.3***.

Water diversion and abstraction will require the approval from Ministry of Water Resources and Meteorology (hereinafter referred to as "MOWRAM").

Table 2.2.3 Laws and Regulations Related to Water Resources Management and Intake

NO.	LAW AND REGULATION	DESCRIPTION
1	Law on Environmental Protection and Natural Resource Management (1996)	As the principal law on environmental protection, the law provides for a national environment policy, national and regional environment plans, assessment of impact on the environment of projects and activities, management of natural resources, monitoring etc.
2	Sub-decree No. 27 on Water Pollution Control (1999)	This sub-decree regulates activities that cause pollution in public water areas to sustain good water quality so that the protection of human health and the conservation of biodiversity are ensured.
3	Law on Water Resources Management (2007)	This law gives MOWRAM responsibility for resource management and water allocation.

Source: JICA Data Collection Survey Team

(3) Regulation on Water Tariff Determination Mechanism

The Ministry of Industry, Science, Technology, and Innovation (hereinafter referred to as "MISTI") Regulation (Prakas) No. 069 dated 4th March, 2016 on the Water Tariff Determination Mechanism divided the water tariff determination mechanism into two methods:

Method 1: Cash Flow Method - This method is converts the cash flow of the water service provider into real value (basic year) to determine the water tariff. This provision applies to "Type A" water service suppliers that supply water to more than 2,001 connections.

Method 2: Annuity Method - This method sets the average water tariff equal to the income of the water service provider divided by the amount of planned water sold. This provision applies to "Type B" water service suppliers that supply water to less than 2,001 connections.

In order to revise water tariffs in Cambodia, PPWSA submits a tariff revision plan to MISTI using one of the above-mentioned calculation methods. The plan is deliberated within MISTI and the National Committee will scrutinize the need for revisions and adequacy of the plan, and final approval is determined with the approval of the Prime Minister. The evaluation of the tariff revision includes financial conditions of PPWSA as well as macroeconomic impacts of the revisions. Therefore, the plans submitted by PPWSA are often modified to meet these other requirements.

Tariffs were revised in 2017 and 2020 using estimation Method 2 stated above (refer to 9-3-4-1 for tariff revision details at PPWSA).

(4) Cambodian National Drinking Water Quality Standards

"National Drinking Water Quality Standards" prepared by MISTI in 2015 is shown in ***Table 2.2.4*** below.

Table 2.2.4 National Drinking Water Standard

NO.	PARAMETER	UNIT	PERMISSIBLE LIMIT	MONITORING FREQUENCY	CONDITION
PHYSICAL					
1	Colour	TCU	5.0	Daily	
2	pH	-	6.5-8.5	Daily	
3	TDS or Conductivity	mg/l or µS/cm	800 or 1600	Daily	
4	Turbidity	NTU/FTU	5.0	Daily	
5	Taste and Odour	-	Acceptable	Daily	
MICROBIAL					
6	E.Coli or Thermotolerant	CFU or MPN/100ml	0	Quarterly	
CHEMICAL					
7	Aluminium (Al)	mg/L	0.2	Quarterly	if alum is used
8	Ammonia (NH_3)	mg/L	1.5	Quarterly	
9	Arsenic (As)	mg/L	0.05	Annually	for groundwater sources
10	Barium (Ba)		0.7	Annually	
11	Cadmium (Cd)	mg/L	0.003	Annually	
12	Chloride (Cl^-)	mg/L	250	Quarterly	if chlorine is used for disinfectant
13	Chlorine Cl_2 (Free Residual)	mg/L	0.1 - 1.0	Daily	
14	Chromium (Cr)	mg/L	0.05	Annually	
15	Copper (Cu)	mg/L	1	Annually	if household plumbing uses copper pipes
16	Fluoride (F)	mg/L	1.5	Annually	for groundwater source
17	Total hardness as $CaCO_3$	mg/L	300	Quarterly	for groundwater source
18	Iron (Fe)	mg/L	0.3	Quarterly	for groundwater source
19	Lead (Pb)	mg/L	0.01	Annually	
20	Mercury (Hg)	mg/L	0.001	Annually	
21	Manganese (Mn)	mg/L	0.1	Quarterly	for groundwater source
22	Nitrate (NO_3^-)	mg/L	50	Quarterly	
23	Nitrite (NO_2^-)	mg/L	3	Quarterly	
24	Sodium (Na)	mg/L	250	Annually	near coastal areas
25	Sulphate Ion SO_4^{2-}	mg/L	250	Quarterly	
26	Zinc (Zn)	mg/L	3	Annually	

Source: MISTI (renamed from MIH in 2020)

(5) Laws and Regulations Related to Environmental and Social Consideration

Prakas No. 21, Classification of Environmental Impact Assessment of Development Projects came into effect 3rd February, 2020. Prior to this, decision on whether an environmental impact assessment (hereinafter referred to as "EIA"), initial environmental impact assessment (hereinafter referred to as "IEIA"), or an environmental protection contract (hereinafter referred to as "EPC") was required was based on expected environmental impacts of the development project. Prakas No. 21 clearly defines the required assessments according to the classification and scope of the project. It also makes environmental management plan (hereinafter referred to as "EMP") a requirement for issuing EPC. All water treatment and water distribution projects require EPCs.

2.3 CONDITION OF PHNOM PENH WATER SUPPLY AUTHORITY (PPWSA)

2.3.1 Phnom Penh Water Supply Authority (PPWSA)

The Phnom Penh Water Supply Authority (PPWSA) was established in 1997 as a public enterprise and is entrusted with delivering water and developing water supply infrastructure in Phnom Penh. It currently supplies treated water 24 hours a day. NRW is less than 10%. The water supply system of PPWSA is shown in ***Table 2.3.1***. Key performance indicators are given in ***Figure 2.3.1***.

Table 2.3.1 Evolution of Key Indicators of PPWSA

INDICATOR	UNIT	1993	2004	2015	2019
Production capacity	m^3/day	65,000	235,000	430,000	540,000
Distribution network	km	280	1,084	2,460	3,353
Supply duration	h/day	10	24	24	24
Tariff collection ratio	%	50	99.9	99.9	99.9
NRW ratio	%	72	15	8.5	10

Source: JICA Data Collection Survey Team based on Third Master Plan and PPWSA PI data

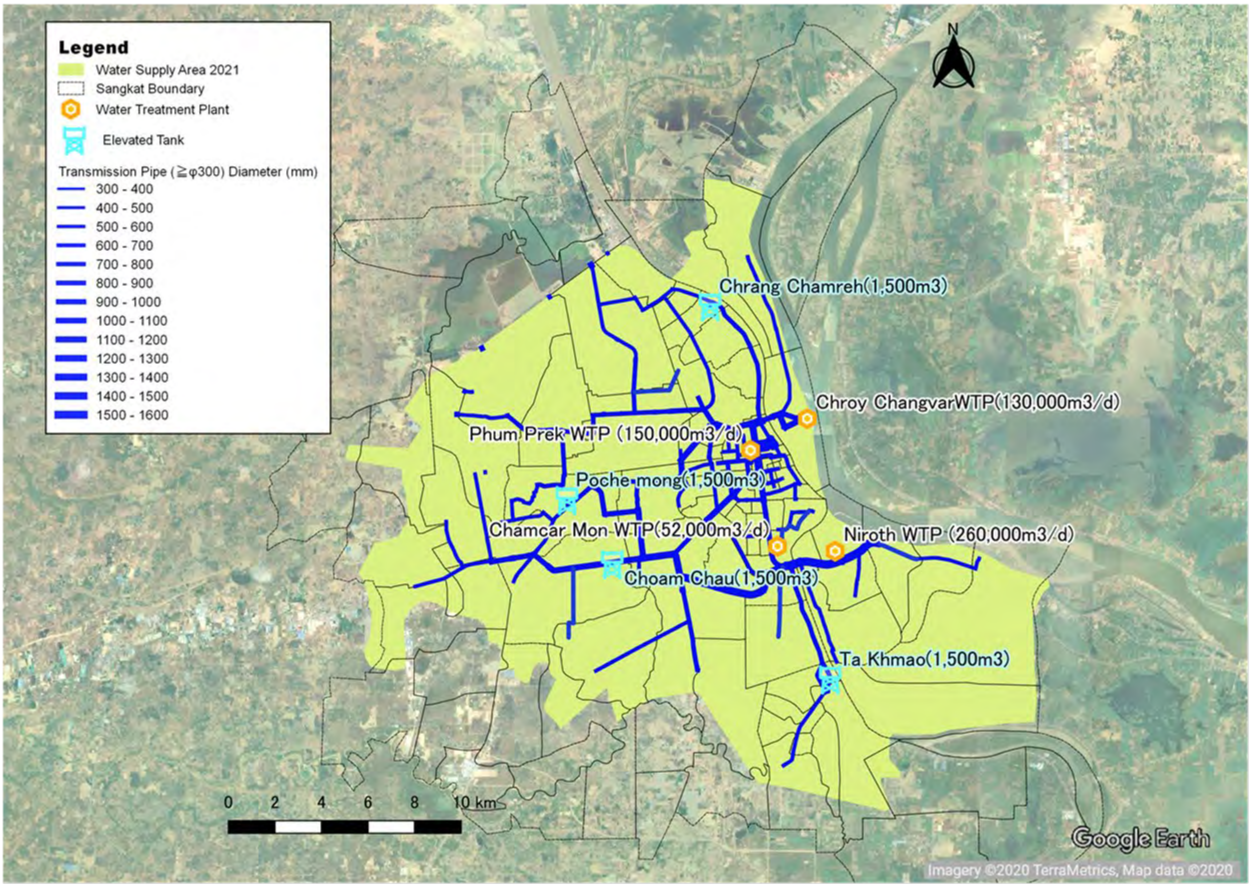


Figure 2.3.1 Existing PPWSA Service Area

Source: JICA Data Collection Survey Team based on Third Master Plan and PPWSA interview

2.3.2 History of ODA Assistance

Grant and loan assistance provided to PPWSA in the past are summarized in ***Table 2.3.2***. Donating agencies and the proportion of total assistance to PPWSA are summarized on ***Figure 2.3.2***.

Table 2.3.2 Grants and Loans Provided to PPWSA

NO.	DESCRIPTION		PROJECT NAME	LOAN & GRANT NO.	AMOUNT	AMOUNT EQUIVALENCE LOAN & GRANT		TOTAL USD	
						EX.RATE	USD	USD	%
		WB						**$36,956,990.42**	**7.34%**
1	Grant	UNDP/WB 1993-1994	-Improvement of customer surveys and record keeping		$2,803,001.00		$2,803,001.00	$2,803,001.00	
2	Loan	1998-2004	Urban Water Supply Project	3041-KH	$23,966,507.00			$23,966,507.00	
3	Loan	2003-2008	Provincial and Peri-Urban Water and Sanitation Project	3746-KH	SDR8,030,892.70	1SDR= 1.467	$9,398,417.11	$9,398,417.11	
	Grant			H034-KH	SDR500,000		$789,065.31	$789,065.31	
		ADB						**$12,745,194.00**	**2.53%**
4	Loan	1997-2003	Phnom Penh Water Supply and Drainage Project	1468-CAM(SF)	$12,745,194.00			$12,745,194.00	
		Japan Govt/JICA			**¥12,100,716,801.00**			**$118,030,790.02**	23.44%
5	Grant	JP Govt 1993-1994	-Master Plan-Target 2010		¥7,888,000,000.00	114/USD	$69,192,982.45	$69,192,982.45	
		1995-1999	-Repair Phum Prek Treatment Plant, increasing the Capacity						
			from 50,000m3/d to 100,000m3/d (Phase 1)						
			-Replacement of supply networks, 52km, in 7 Makara and						
			part of Tuol Kork district (Phase 2)						
	Grant	2001-2003	-Expansion of Phum Prek Treatment Plant, capacity reached 150,000m3/day						
	Grant	2004-2006	-Remaster Plan- Target 2020						
	Grant	2003-2006	-Capacity Building for Water Supply System in Cambodia						
6	Grant	JICA 2010-2013	Project for Introduction of Clean Energy by Solar Electricity Generation System	No.0962090	¥720,000,000.00	90/USD	$8,000,000.00	$8,000,000.00	
7	Loan	2009-2013	Niroth Water Supply Project -Phase I (Part B)	No.CP-P9	¥3,492,716,801.00	109/USD	$40,837,807.57	$40,837,807.57	
		France Govt						**$14,770,607.98**	**2.93%**
8	Grant	1995-1998	Phum Prek Reservoir Restoration & Filter Backwash Equip. replacement, and Expansion of Chamcarmon Treatment Plant		Fr. 79,200,000.00	5.75/USD	$14,770,607.98	$14,770,607.98	
		AIMF France						**$514,957.24**	**0.10%**
9	Grant	2006-2007	Agreement for funding and assistance for Project Implementation (S&D of HDPE fitting and Valves for Sen Sok Community)		200,000.00 €	1.5/EUR	$300,000.00	$300,000.00	
10	Grant	2009	Supply and Delivery of HDPE and DI Pipes & Fittings Project for Phum Trapaing Achanh & Phum Ondoung		163,000.00 €		$214,957.24	$214,957.24	
		Marie de Paris						**$200,085.81**	**0.04%**
11	Grant	2007-2010	Clean Water for all Project (Household connection)		150,000.00 €		$200,085.81	$200,085.81	
		AFD						**$205,363,167.31**	**40.78%**
12	Grant	2003-2008	The Extension of Phnom Penh Suburb Water Supply System	CKH1055 01M	4,000,000.00 €	1.5/EUR	$6,000,000.00	$6,000,000.00	
13	Grant	2009(4M)	Feasibility Study of the Sourth Branch of Phnom Penh Transmission Main	CKH 3007 01L	$100,000.00			$100,000.00	
	Grant			CKH 1089 01V					
14	Grant	2012	Extension of Water Supply System to the Greater PP (GPPWSS)	FERC CKH 111	250,322.00 €	1.4/EUR	$350,450.80	$350,450.80	
15	Loan	2007-2009	The Extension of Chrouy Changwar Water Treatment Plant (PhaseII)	CKH6000 01G	10,765,265.75 €	1.5/EUR	$16,147,898.63	$16,147,898.63	
16	Loan	2009-2013	Niroth Water Supply Project (Phase 1)	CKH 1075 03S	15,982,922.32 €	1.5/EUR	$23,974,383.48	$23,974,383.48	
			Raw Intake Station and Raw Water Transmission Mains						
17	Loan	2013-2017	Niroth Water Supply Project (Phase 2) include Feasibility below	CKH 1121 01F	30,000,000.00 €	1.25/EUR	$37,500,000.00	$37,500,000.00	
18	Grant	2015	Feasibility Study for Northern-Western Resource and Technical Assistance for Zoning Activities Implementation (share from FASEP) - (money withdraw from Loan 1121 01F by Add No.1 on Contract Safege)		318,245.00 €	1.12/EUR	$356,434.40	$356,434.40	
19	Loan	2017-2020	The Extension of Chamcar Morn Water Production Facilities and Distribution System	No.1174 01P	30,000,000.00 €	1.19/EUR	$35,934,000.00	$35,934,000.00	
20	Loan	2018-2022	Bakheng Water Supply Project	CKH1176 01S	77,300,000.00 €	1.09/EUR	$85,000,000.00	$85,000,000.00	
		EIB						**$115,000,000.00**	22.84%
21	Loan	2018-2022	Bakheng Water Supply Project - A	FI N°89008			$100,000,000.00	$100,000,000.00	
22	Grant	EU	Bakheng Water Supply Project - A				$15,000,000.00	$15,000,000.00	
			Total Grant and Loan					**$503,581,792.78**	**100.00%**

Source: PPWSA

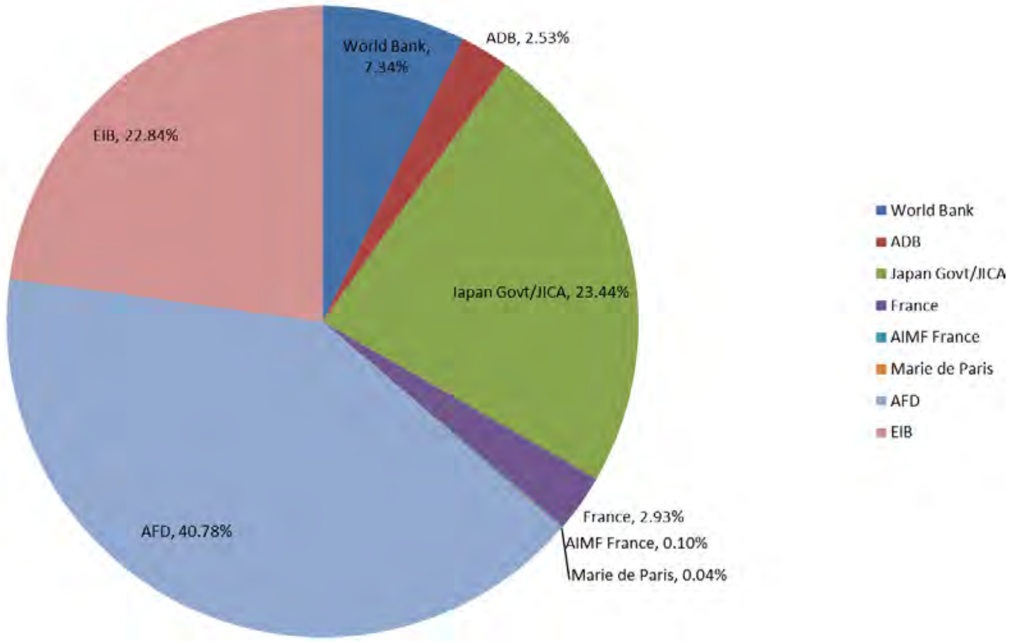


Figure 2.3.2 Donating Agencies and Proportion of Total Assistance to PPWSA
Source: PPWSA

2.3.3 On-going and Planned Projects

Projects under way or under planning by PPWSA are summarized in ***Table 2.3.3***.

Table 2.3.3 On-going and Planned Projects

ITEM	DESCRIPTION
Project title	**The Project for Construction of Water Treatment Plant in Bakheng Phase I**
Target year of commencing operation	Construction (2018-2023), Operation (2023)
Finance source	AfD (Loan), EIB (Loan and grant), PPWSA
Project component	Component 1: Construction of the Bakheng Water Production Facility (180,000 m^3/day) Component 2: Reinforcement and extension works of the network Component 3: Technical assistance
Project cost	USD 247,000,000
Project status	Under construction
Project title	**Bakheng Water Supply Project Phase I**
Target year of commencing operation	Construction (2020-2023)
Finance source	EU (Grant)
Project component	The Supply and Delivery of distribution systems for Low Income Household
Project cost	USD 15,000,000
Project status	Under preparation
Project title	**The Project for Construction of Water Treatment Plant in Bakheng Phase II**
Target year of commencing operation	Construction (2022-2023), Operation (2023)
Finance source	AfD (Loan)
Project component	Component 1: Water Production Facility (195,000 m^3/day) Component 2: Network extension Component 3: Engineering and water supply improvement
Project cost	USD 134,400,000
Project status	Under construction
Project title	**The Project for the Expansion of Water Supply System in Ta Khmau**
Target year of commencing operation	Construction (2022-2024), Operation (2024)
Finance source	Japan Govt/JICA (Grant)
Project component	Construction of the Ta Khmau Water Treatment Plant (30,000 m^3/day)
Project cost	Under Japanese Grant
Project status	Under Tendering

ITEM	DESCRIPTION
Project title	**The Project for the Expansion of Phum Prek Water Supply System**
Target year of commencing operation	Construction (2026), Operation (2026)
Finance source	Japan Govt/JICA (Grant)
Project component	Expansion of Phum Prek Water Treatment System from 150,000 m^3/day to 195,000 m^3/day
Project cost	Under Japanese Grant
Project status	Under planning

Source: JICA Data Collection Survey Team based on PPWSA

CHAPTER 3 REVIEW OF THE THIRD MASTER PLAN

3.1 HISTORY OF MASTER PLAN

The Phnom Penh Water Supply Master Plan has been created twice and updated several times. The summary of these Master Plans and related updates are shown below.

1) The First Master Plan

The water supply system in Phnom Penh, the capital of the Kingdom of Cambodia, was severely deteriorated due to prolonged lack of operation and maintenance of the facilities during the civil war that ended in 1991. At that time, production capacity was only 63,000 m^3/day, supply was intermittent, and most water produced was lost or stolen. Considering the situation, the Japanese International Cooperation Agency (hereinafter referred to as “JICA”) financed to create the Master Plan of the Water Supply System from 1993-2010 (The First Master Plan). The works defined in the First Master Plan were carried out through the efforts of PPWSA with assistance from several donors and financing agencies. They included:

- Rehabilitation of Chamcar Mon (+2,000 m^3/day) and Phum Prek (+45,000 m^3/day) Water Production Facilities in 1995
- Expansion of Chamcar Mon WTP (+10,000 m^3/day) in 1997
- Construction of Chroy Changvar WTP Phase I (65,000 m^3/day) in 2002
- Expansion of Phum Prek WTP (+50,000 m^3/day) in 2003

In 10 years, PPWSA increased the water supply capacity to 235,000 m^3/day and expanded the served population to around 800,000 people in 2004. A very effective Non-Revenue Water (hereinafter referred to as “NRW”) management policy reduced NRW from around 70% to below 10%. Financial performance was dramatically improved and PPWSA started making profit.

2) The Second Master Plan (M/P 2006)

In 2004, considering the increasing water demand, JICA agreed to finance the study on the Second Master Plan (hereinafter referred to as “The Second Master Plan (M/P 2006)”) of Greater Phnom Penh Water Supply over the period 2005-2020. Target production capacity was 500,000 m^3/day in 2020. The Second Master Plan included two projects for expansion of production capacity:

- Chroy Changvar WTP Phase II (65,000 m^3/day) planned in 2007
- Nirodh WTP Phase I and Phase II (100,000 m^3/day each) planned in 2013 and 2019
- Construction of Chroy Changvar WTP Phase II began in 2007 and production started in 2009. At that point, total production capacity was 300,000 m^3/day and population served reached around 1.5 million people.

In the meantime, PPWSA consolidated its technical and financial performance by maintaining NRW below 10% and further increasing profitability.

3) Updates of the Second Master Plan (France 2008 and M/P 2013)

In 2008, water demand was increasing much faster than anticipated during the Second Master Plan preparation. A first update of the Second Master Plan (hereinafter referred to as “France 2008”) showed that the capacity of Nirodh WTP needed to be 130,000 m^3/day for each phase instead of 100,000 m^3/day, and that they would be needed in 2011 and 2015, respectively.

Construction of Nirodh WTP Phase I began in 2010 and production started in 2013. In 2011 water demand started to exceed production capacity, as predicted in the update of the Second Master Plan. In 2011, 20 new communes were included in the administrative perimeter of the Capital City of Phnom Penh further increasing the demand base of the PPWSA service area.

A second update of the Second Master Plan (hereinafter referred to as “M/P 2013”) was performed in 2012 to study the water supply of those 20 communes and plan expansions of the transmission network associated with Nirodh WTP Phase II.

Construction of Nirodh WTP Phase II started in 2014 and was completed in 2016. As predicted in the second update of the Second Master Plan, total water demand exceeded production capacity again in 2015.

4) Third Master Plan (M/P 2017)

The Third Master Plan (M/P 2017) was developed in 2015 for the period 2016-2030 to:

- Achieve sustainable expansion of the Greater Phnom Penh Water Supply System (GPPWSS), and to reach 100% coverage by the end of the period.
- Prepare the Feasibility Study, Preliminary Engineering Design, and Tender Documents for the priority projects.

The Third Master Plan (M/P 2017) was submitted in December 2016 and revised in March 2017 following presentation and discussion with PPWSA.

Areas surveyed in the Third Master Plan (M/P 2017) are shown in ***Figure 3-1.1***.

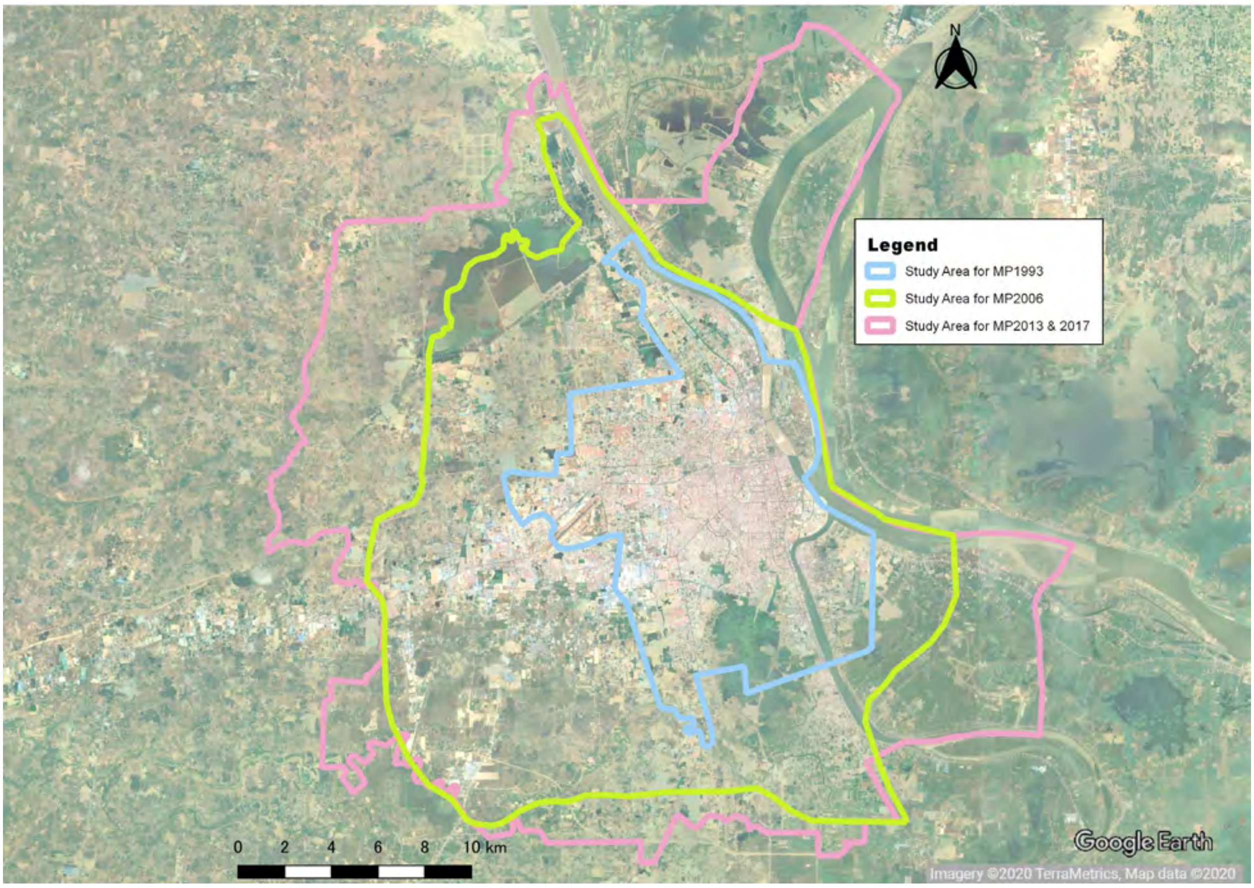


Figure 3-1.1 Survey Areas of the Third Master Plan (M/P 2017)

Source: JICA Data Collection Survey Team

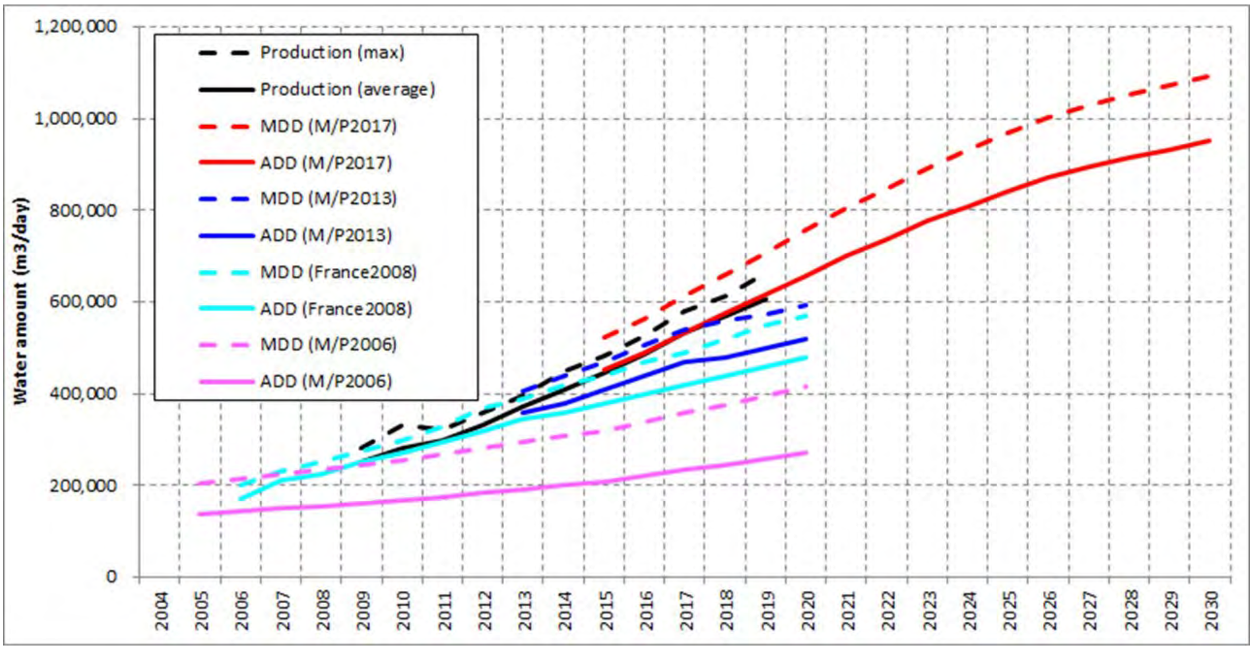
3.2 REVIEW OF WATER DEMAND FORECAST

3.2.1 Past Water Demand Forecasts

(1) Comparison of Past Water Demand Forecasts

Figure 3.2-1 shows the actual production and water demand projections of the past water demand forecasts. The Third Master Plan (M/P 2017) indicated the following regarding these projections:

- The water demand forecast in M/P 2006, which was carried out based on population projections, do not reflect actual situations.
- The water demand forecast by France 2008 was accurate for the first 4-5 years but underestimates the actual increase in demand thereafter.
- The water demand forecast by M/P 2013 was higher than those estimated in 2009, but still underestimates actual demand (probably even more so after 2017).



ADD: Average Day Demand
MDD: Maximum Day Demand

Figure 3.2-1 Comparison of Past Water Demand Forecasts and Total Water Production

Source: M/P 2006, France 2008, M/P 2013 and M/P 2017

From ***Figure 3.2-1***, the water demand forecast of the Third Master Plan (M/P 2017) is almost the same as the actual production amount. However, it does not mean that the water demand forecast of the M/P 2017 is reasonable. The water demand forecast of the M/P 2017 actually underestimated water demands from the following reasons:

- All of the WTPs are operating under overload conditions in recent years.
- If the capacity of the existing WTPs was sufficient, the amount of water supplied would be higher.
- There is unmet water demand, which cannot be billed for because the water was never treated or consumed.
- Therefore, the water demand forecast of the Third Master Plan (M/P 2017) should be higher than the current forecast.

(2) Water Production

Figure 3.2-2 to ***Figure 3.2-6***, and ***Figure 3.2-2*** show the total volume of water treated by WTPs in Phnom Penh.

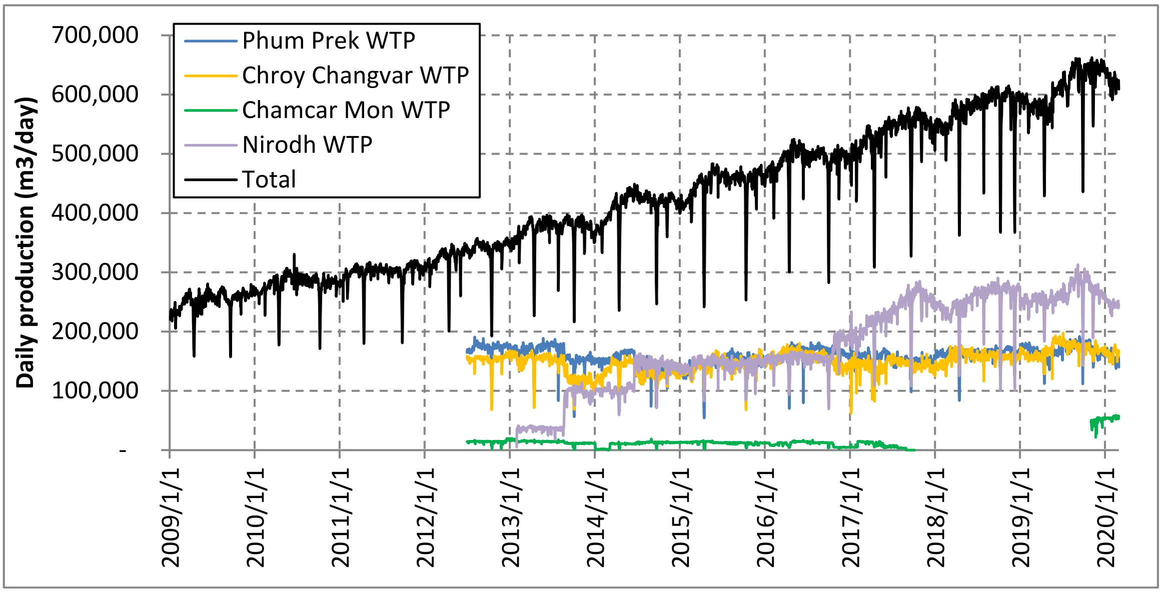


Figure 3.2-2 Comparison of water production of each WTP

Source: JICA Data Collection Survey Team based on the data provided by PPWSA

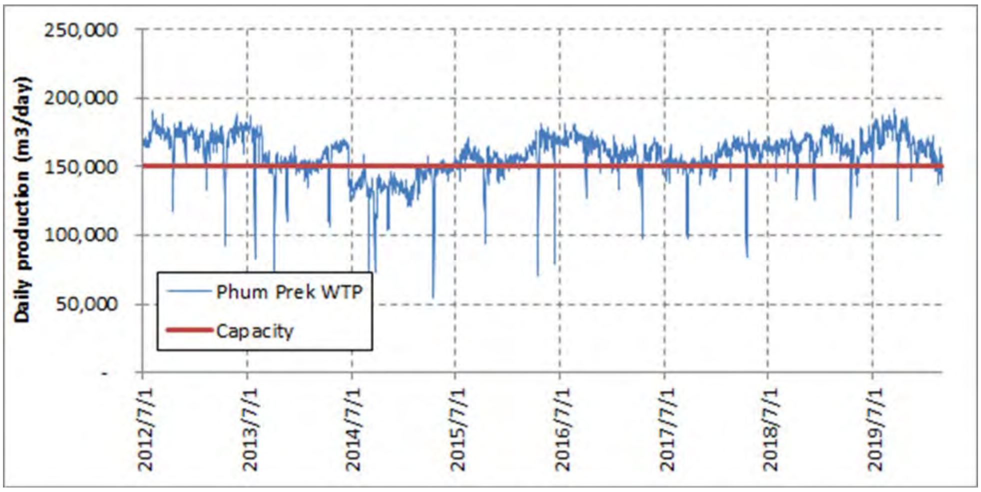


Figure 3.2-3 Water production of Phum Prek WTP

Source: JICA Data Collection Survey Team based on the data provided by PPWSA

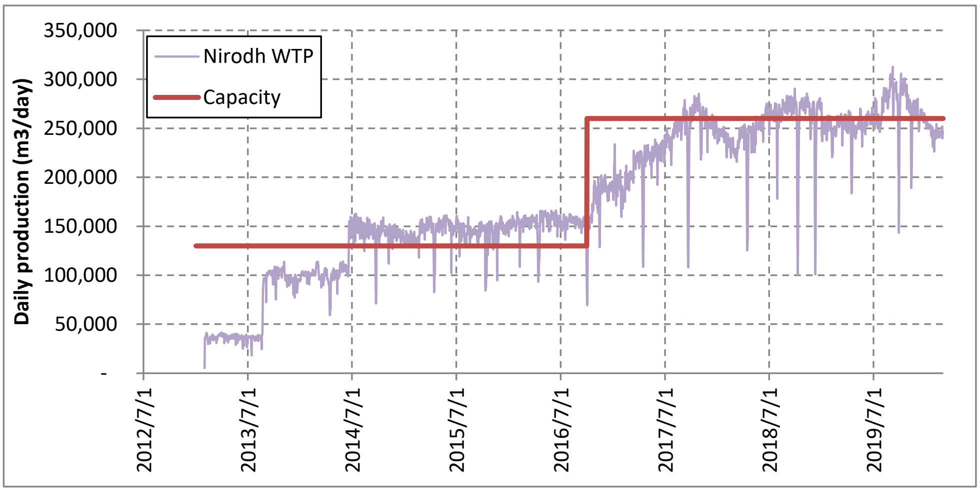


Figure 3.2-4 Water production of Nirodh WTP

Source: JICA Data Collection Survey Team based on the data provided by PPWSA

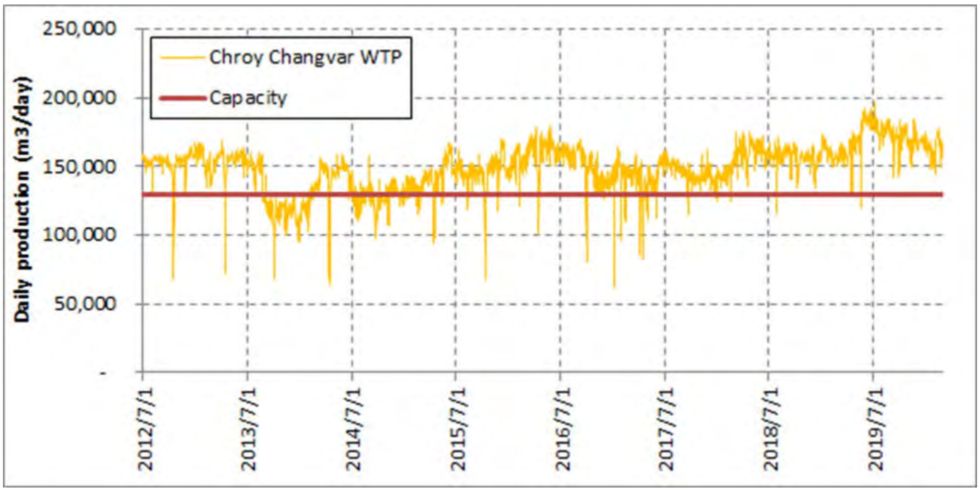


Figure 3.2-5 Water production of Chroy Changvar WTP

Source: JICA Data Collection Survey Team based on the data provided by PPWSA

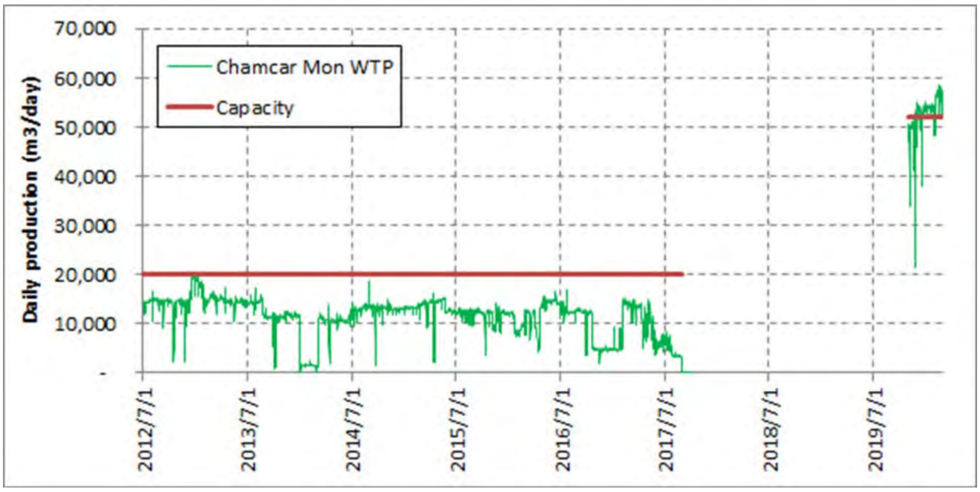


Figure 3.2-6 Water production of Chamcar Mon WTP

Source: JICA Data Collection Survey Team based on the data provided by PPWSA

Following situations are observed from these production records:

- Phum Prek WTP has been operating under overload conditions most of the time except for short periods. The average operation rate[1] has been 106 % from 2012 to 2020.
- Chroy Changvar WTP has been operating under overload conditions most of the time except for short periods. The average operation rate has been 114 % from 2012 to 2020.
- Chamcar Mon has been expanded and recommissioned from November 2019. The WTP has been operating at almost full capacity of the reduced capacity since the recommissioning.
- Nirodh WTP has been operating under overload conditions except for some periods such as part of 2016 and 2017. The average operation rate has been 100% from 2013 to 2020.

Figure 3.2-7 shows the total production and capacity of all the WTPs in Phnom Penh, and ***Figure 3.2-8*** shows the operation rate and total capacity of all the WTPs in Phnom Penh.

[1] * Operation rate is calculated by the following formula: Operation rate = Production amount / Capacity

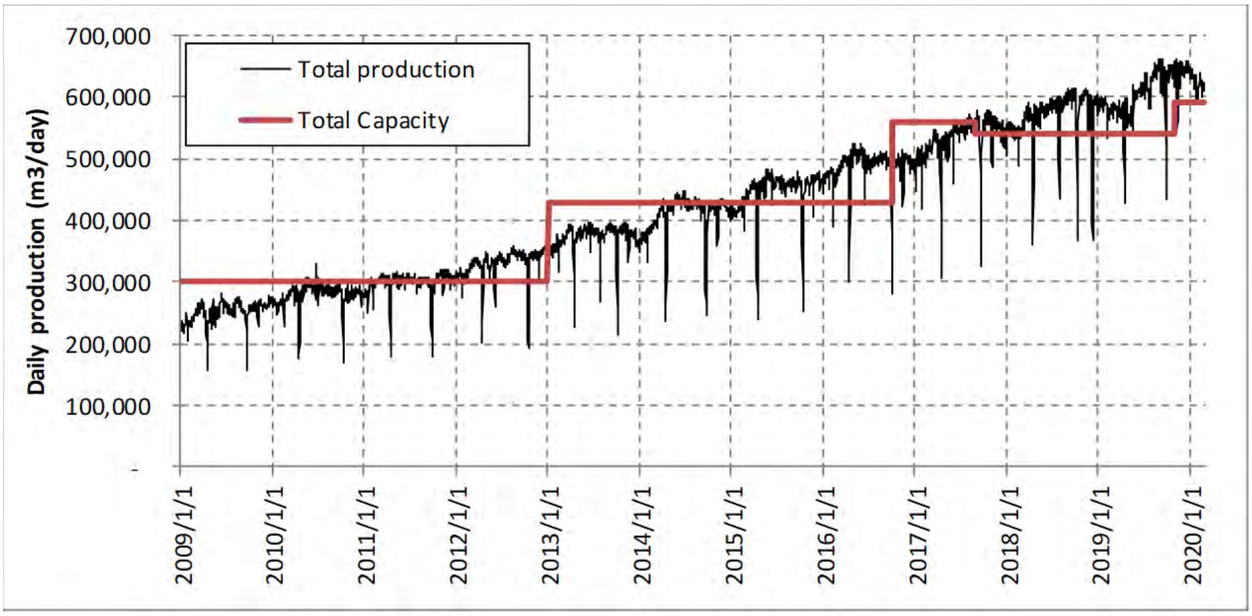


Figure 3.2-7 Total water production and total capacity of above 4 WTPs
Source: JICA Data Collection Survey Team based on the data provided by PPWSA

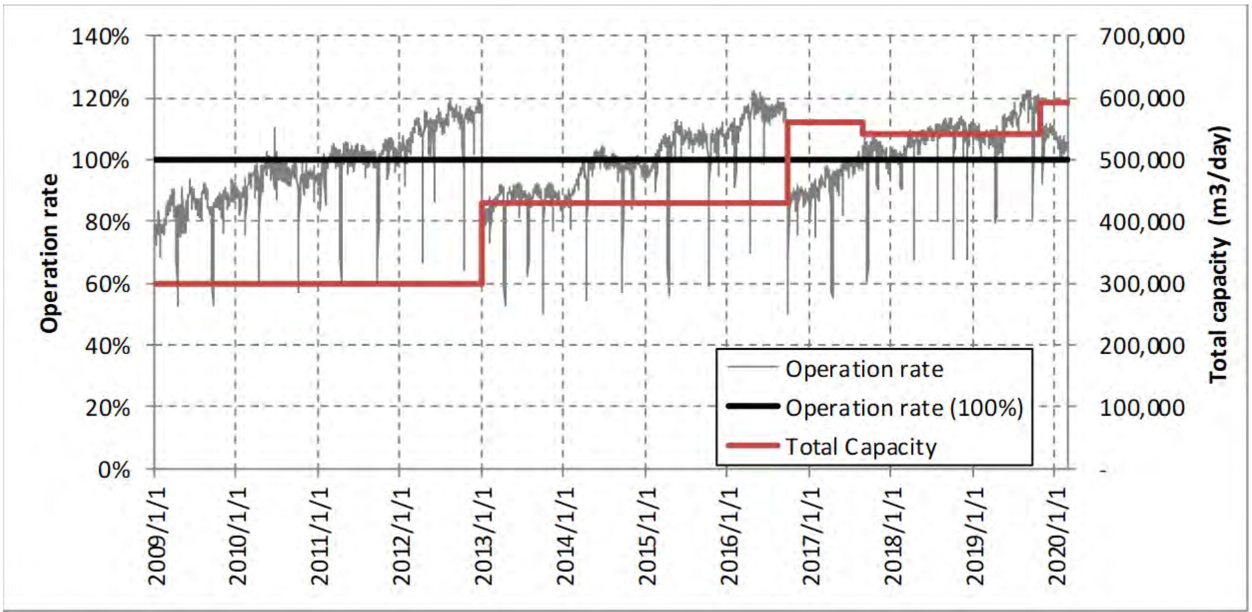


Figure 3.2-8 Total operation rate and total capacity of above four WTPs
Source: JICA Data Collection Survey Team based on the data provided by PPWSA

The following situations are observed from ***Figure 3.2-7*** and ***Figure 3.2-8***.

- The total capacity was greater than total production until 2014 except for a period from 2011 to 2013.
- The recent treatment volume is greater than the total treatment capacity.

In studying the water demand, it should be noted that treatment volume has exceeded treatment capacity in recent years. This creates the possibility that water required by consumers is not available in sufficient amounts and water consumption alone does not give an accurate picture of actual demand.

3.2.2 Methodologies of Past Water Demand Forecasts

(1) Summary of Methodologies of Past Water Demand Forecasts

Methodologies of the past water demand forecasts is summarized in ***Table 3.2.1***.

Table 3.2.1 Summary of Methodologies of Past Water Demand Forecasts

STUDY	SUMMARY OF METHOD
M/P 2006	Forecast period: 2005-2020 Projection was carried out mainly based on the following parameters for each district (Total: 7 districts and Kandal province). − Population forecast − Consumption per person (domestic) − Water supply coverage − Consumption for non-domestic category
M/P 2013	Forecast period: 2013-2020 Projection was carried out mainly based on the following parameters for each district. − Pipe length (km) − Connection/pipe length (km) − Consumption per connection (domestic, non-domestic, administrative) − Proportion of connection (domestic, non-domestic, administrative)
M/P 2017	Forecast period: 2015-2030 Projection was carried out mainly based on the following parameters for each Sangkat (total: 92). − Connection density (connection/ha) − Proportion of connection (domestic, non-domestic) − Consumption per connection (domestic, non-domestic)

Source: M/P 2006, M/P 2013, M/P 2017

The reasons that the water demand forecasts in the Second Master Plan (M/P 2006) and in the Update of the Second Master Plan (M/P 2013) underestimated actual demand are explained in the Third Master Plan (M/P 2017) as follows:

- The methodology in the Second Master Plan (M/P 2006) based on population projections did not anticipate or account for:
  - the current urban population explosion, and
  - internal migration, i.e., people living, working, and consuming water in Phnom Penh, without being registered as residents there.

- The methodology in the Updated of the Second Master Plan (M/P (2013):
  - It is extremely difficult to forecast 10 or 15 years into the future based on the length of pipes to be laid yearly. For this reason, this method is usually only used for 5-year forecasts, after which demand growth is based on population projection. That is why the 2008 forecasts are accurate until 2012, but underestimate actual demand thereafter,
  - For hydraulic modelling and transmission mains, it is better to forecast water demand at the Sangkat (commune) level. However, this cannot be achieved because it is even harder to forecast accurately the length of pipes to be laid and the connection density to be achieved in each Sangkat for each year, and
  - For forecasting purposes, water demand was divided into three categories: domestic, non-domestic, and administrative. However, there were very few customers in the administrative category; therefore, accurate forecasting of future trends was not possible from such a small sample size. (In the Third Master Plan (M/P 2017), administrative demand was included in the non-domestic category for water demand forecasting.)

(2) Methodologies of Past Water Demand Forecasts

1) Second Master Plan (M/P 2006)

M/P 2006 used the following parameters for water demand forecasting:

- Population projection (number of people),
- Estimation of domestic water consumption per person,
- Water supply coverage (%),

- Estimation of non-domestic water consumption.

Summary on methodology to calculate these parameters is shown below.

- Population projection:
  - Basic data of population and the number of households by commune from Census 1998.
  - Population in each commune from 2005 to 2020 will change to reach the target population density set for 2020.
  - The target or planned population densities are determined based on the values obtained from BAU (Bureau of Urban Affairs) of the Municipality of Phnom Penh.
  - Summary of population projection is as follows:

Table 3.2.2 Summary of Population Projection in M/P 2006

Year	2005	2010	2015	2020
Municipality of Phnom Penh	1,334,892	1,551,479	1,776,646	2,006,009
Phnom Penh Central 4 Districts	715,532	704,810	694,088	683,360
Phnom Penh Suburb 3 Districts	619,360	846,669	1,082,558	1,322,649
Kandal Province	195,107	223,412	258,222	297,817
Study Area Total	**1,529,999**	**1,774,891**	**2,034,868**	**2,303,826**

Source: M/P 2006

- Estimation of domestic consumption per person:
  - Based on the unit consumption level in 2004, unit consumption in the target year 2020 was computed at five consumption levels: 90, 95, 100, 110, and 130 liters per capita per day in accordance with the applied growth rate of 1%, 2%, or 3% as shown in ***Table 3.2.3***.

Table 3.2.3 Applied Scenario for Unit Consumption Rate Increase

Classification	2005	2010	2015	2020
Scenario A: 1% growth				
High consumption areas	80	85	90	95
Low consumption areas	70	80	85	90
Scenario B : 2% growth				
High consumption areas	80	90	100	110
Low consumption areas	70	80	90	100
Scenario C: 3% growth				
High consumption areas	80	95	110	130
Low consumption areas	70	80	95	110

Source: M/P 2006

- Water supply coverage:
  - Water supply coverage was used to calculate the consumption for domestic category.
  - Water supply coverage was planned as shown in ***Figure 3.2-9***.

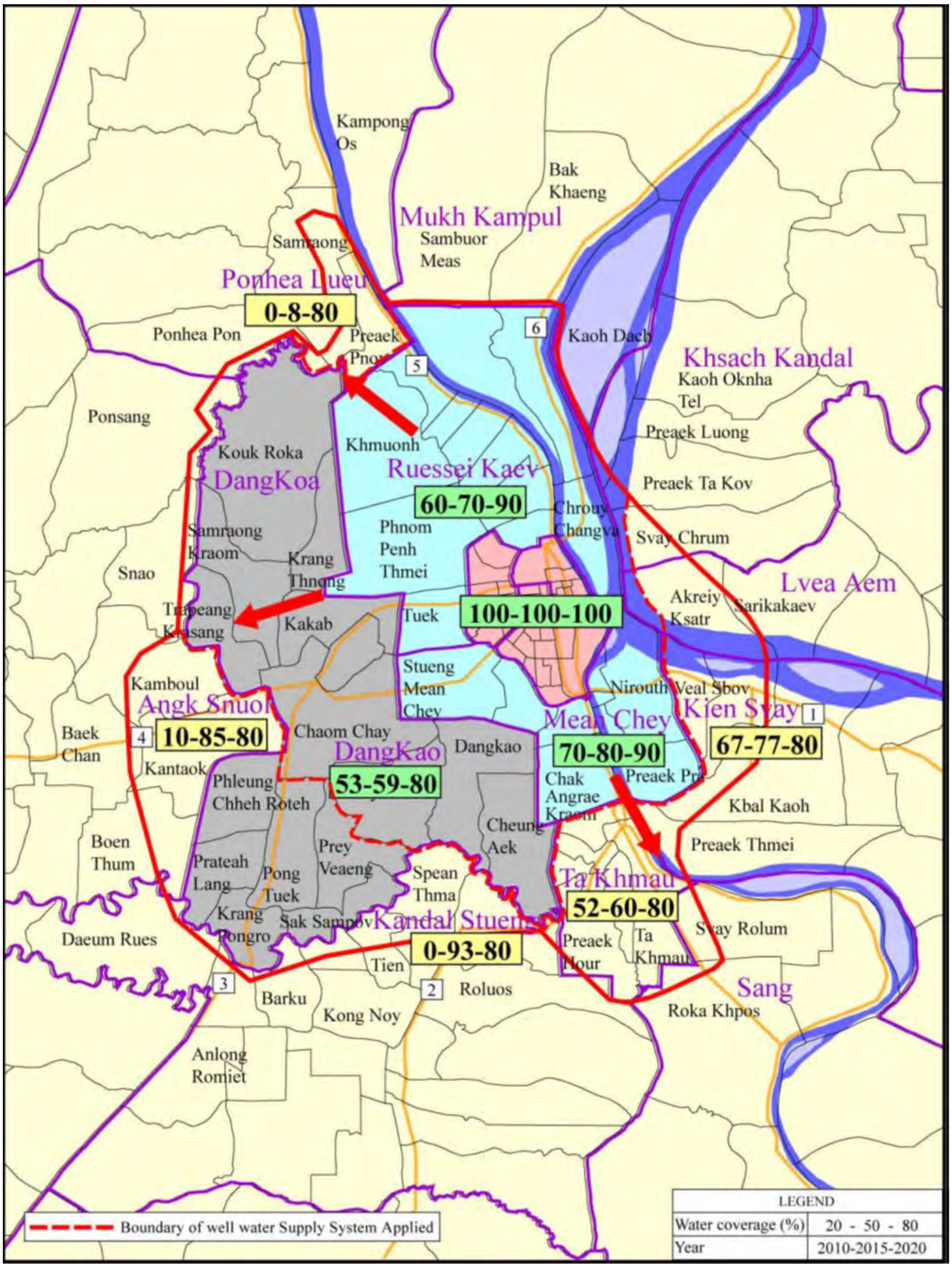


Figure 3.2-9 Planned Water Supply Coverage in M/P (2006)
Source: M/P 2006

- Estimation of non-domestic consumption for:
  - Non-domestic consumption in future is calculated based on the non-domestic consumption in 2004 as shown in ***Table 3.2.4***.

Table 3.2.4 Non-Domestic Consumption in 2004

	Commercial	Administrative	Others	Total
Chamkar Mon	7,939	2,562,	55	10,556
Doun Penh	7,974	4,883	271	13,128
7 Meakkara	4,019	1,194	119	5,332
Tuol Kouk	6,427	1,234	10	7,671
Dangkao	4,025	232	**0**	4,257
Mean Chey	4,690	128	**2**	4,820
Ruessei Kaev	4,268	413	12	4,692
Kandal	**216**	**55**	**0**	271
Total	**39,377**	**10,654**	**458**	**50,490**

Source: M/P 2006

- The formula below is applied to calculate the future consumption for non-domestic category based on the non-domestic consumption in 2004. The results are as shown in ***Table 3.2.5***.

$y = y_0(1+r)^x$ where, y : non-domestic consumption after x-year from the reference year
y_0 : consumption of the reference year (2004)
r : yearly average increase ratio
x : number of years after the reference year

Table 3.2.5 Non-Domestic Water Demand in Daily Average Basis (m³/day)

Year	2005	2010	2015	2020
Scenario A				
Commercial	39,558	45,305	50,021	55,227
Administrative	10,700	11,400	11,982	12,593
Others	468	525	552	580
Total for Scenario A	**50,726**	**57,230**	**62,554**	**68,400**
Scenario B				
Commercial	39,558	47,976	55,618	64,476
Administrative	10,700	11,400	11,982	12,593
Others	468	525	552	580
Total for Scenario B	**50,726**	**59,901**	**68,151**	**77,649**
Scenario C				
Commercial	39,558	50,780	61,782	75,167
Administrative	10,700	11,400	11,982	12,593
Others	468	525	552	580
Total for Scenario C	**50,726**	**62,705**	**74,315**	**88,340**

Source: M/P 2006

2) Update of the Second Master Plan (M/P 2013)

M/P 2013 forecasted water demand using an alternative method since water demand was underestimated by the Second Master Plant (M/P 2006). That method is based on the following:

- Estimate development of network length and number of connections/km of pipes to give the growth in the total number of connections,
- Estimate the percentage of domestic, non-domestic, and administrative connections, which when multiplied by the estimate of total connections gives the number of connections in each category,
- Estimate the consumption per connection in each category, which when multiplied by the number of connections in each category gives the consumption per category, and
- Estimate the NRW rate, which when combined with the consumption per category, results in total water demand.

Figure 3.2-10 shows how the methodology works. The parameters to be forecast are presented in the orange-coloured boxes, and the results in blue the boxes. ***Figure 3.2-11*** also shows the methodology of the water demand forecast in M/P 2013.

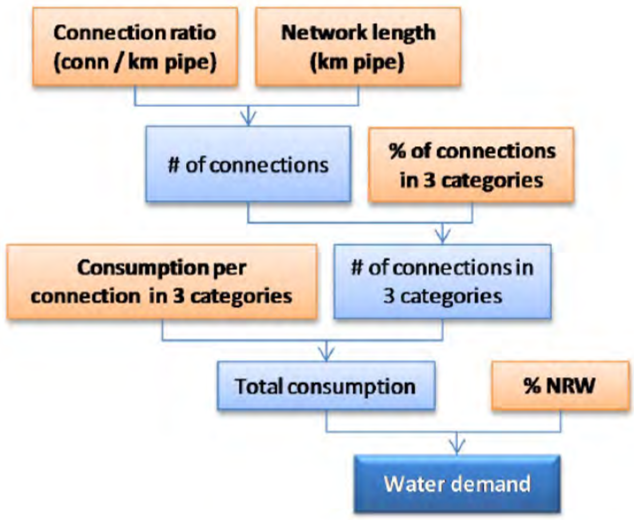


Figure 3.2-10 Methodology for Water Demand Projection Implemented in M/P 2013
Source: M/P 2013

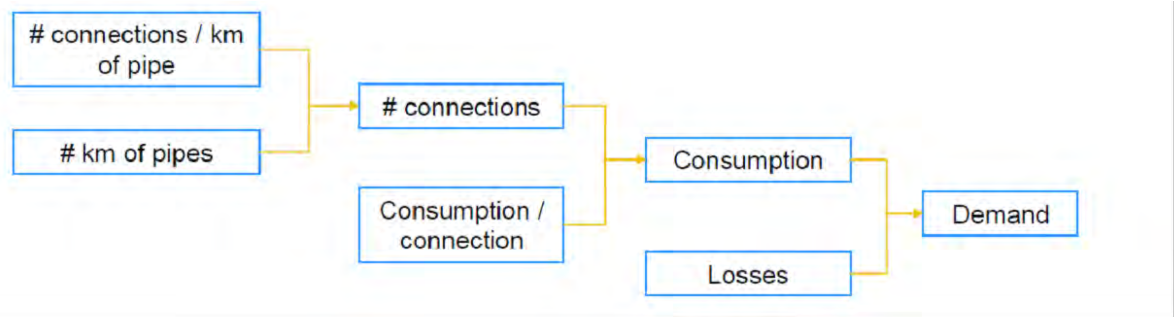


Figure 3.2-11 Method of Water Demand Forecast (M/P 2013)
Source: M/P 2013

3) The Third Master Plan (M/P 2017)

To further improve the accuracy of water demand projections, a new methodology was developed for the Third Master Plan (M/P 2017). It is not based on the length of pipes expected to be laid and connection ratios, but on the connection density (number of connections of any category per hectare of land). The reasons for revising the methodology are as follows:

- The connection density can be directly related to the type of urban landscape in each Sangkat.
- As urban expansion spreads from the central area to the suburbs, it is possible to predict the development of sub-urban areas based on the history of recently developed central areas.
- There is a “physical reality” for understanding changes to connection density, unlike for the km of pipes to be laid or the number of connections per km of pipe.

The water demand predictions are based on forecasts of the following parameters for each Sangkat (including, for each year, expected value and standard deviation):

- Connection density (connections per hectare),
- Percentage of customers that are domestic customers,
- Consumption per domestic connection,
- Consumption per non-domestic connection,

The methodology is summarized in ***Figure 3.2-12***.

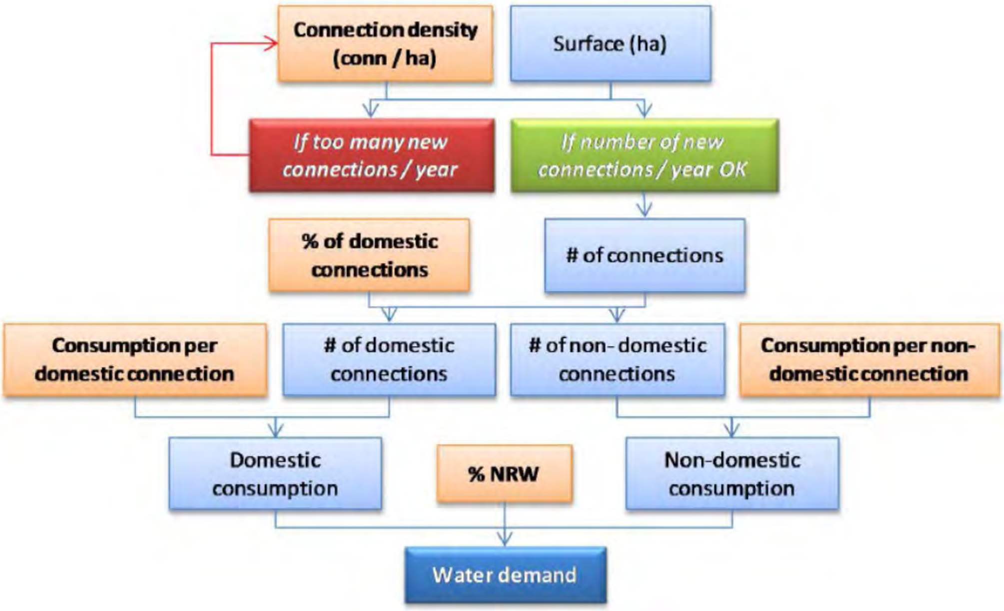


Figure 3.2-12 Methodology for Water Demand Projection Developed in the Third Master Plan (M/P 2017)

Source: Third Master Plan (M/P 2017)

3.2.3 Comparison of Water Demand Forecast and Billing Data of the Third Master Plan (M/P 2017)

(1) Comparisons by Sangkat Level

The examples of the comparison on connection/ha by Sangkat level are shown in ***Figure 3.2-13***. ***Figure 3.2-13*** shows the typical example of the comparisons. All of the other comparisons are shown in the ***Appendix***.

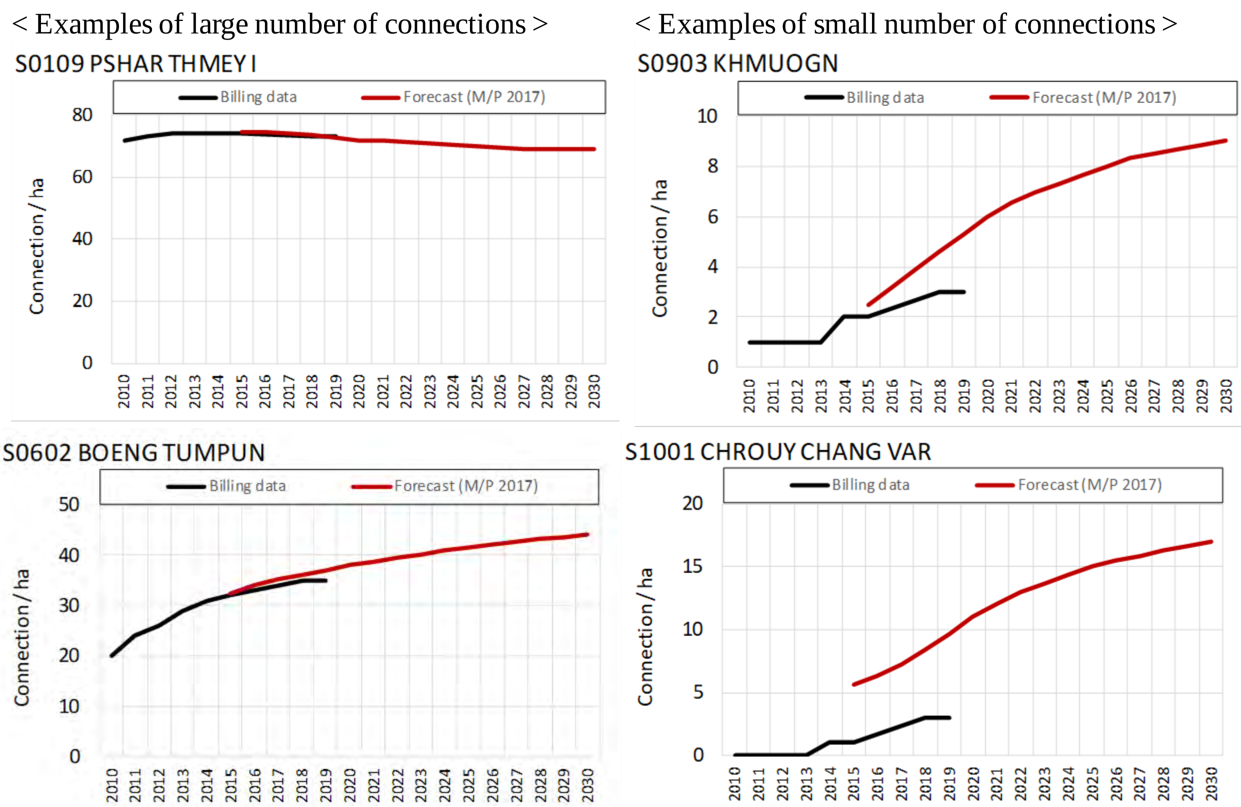


Figure 3.2-13 Comparisons of Water Demand Forecast and Billing Data (Connection/ha)

Source: Third Master Plan (M/P 2017)

According to the comparisons between the water demand forecast of the Third Master Plan (M/P 2017) and billing data at the Sangkat level, the following characteristics were observed:

- Most of the forecasts had same trends with the billing data (2015-2019).
- Some of the forecasts are different from the billing data (2015-2019).
- In the case of Sangkats with a large number of connections, the forecasts tend match the billing data, as shown on left side of ***Figure 3.2-13***.
- In the case of Sangkats with a small number of connections, the forecasts tend not to match the billing data, as shown on right side of ***Figure 3.2-13***.

Based on the above comparisons, the followings conclusions can be reached:

- In case of Sangkats with large number of connections, forecasts tend to be reliable due to clear trends based on the large number of samples.
- In case of Sangkats with small number of connections, forecasts tend to be unreliable due to unclear trends based on the small number of samples.

(2) Comparisons by Khan Level

The examples of the comparison by Khan level are shown in ***Figure 3.2-14***. ***Figure 3.2-14*** shows the example of Ta Khmao for the comparisons. All the other comparisons are shown in the ***Appendix***.

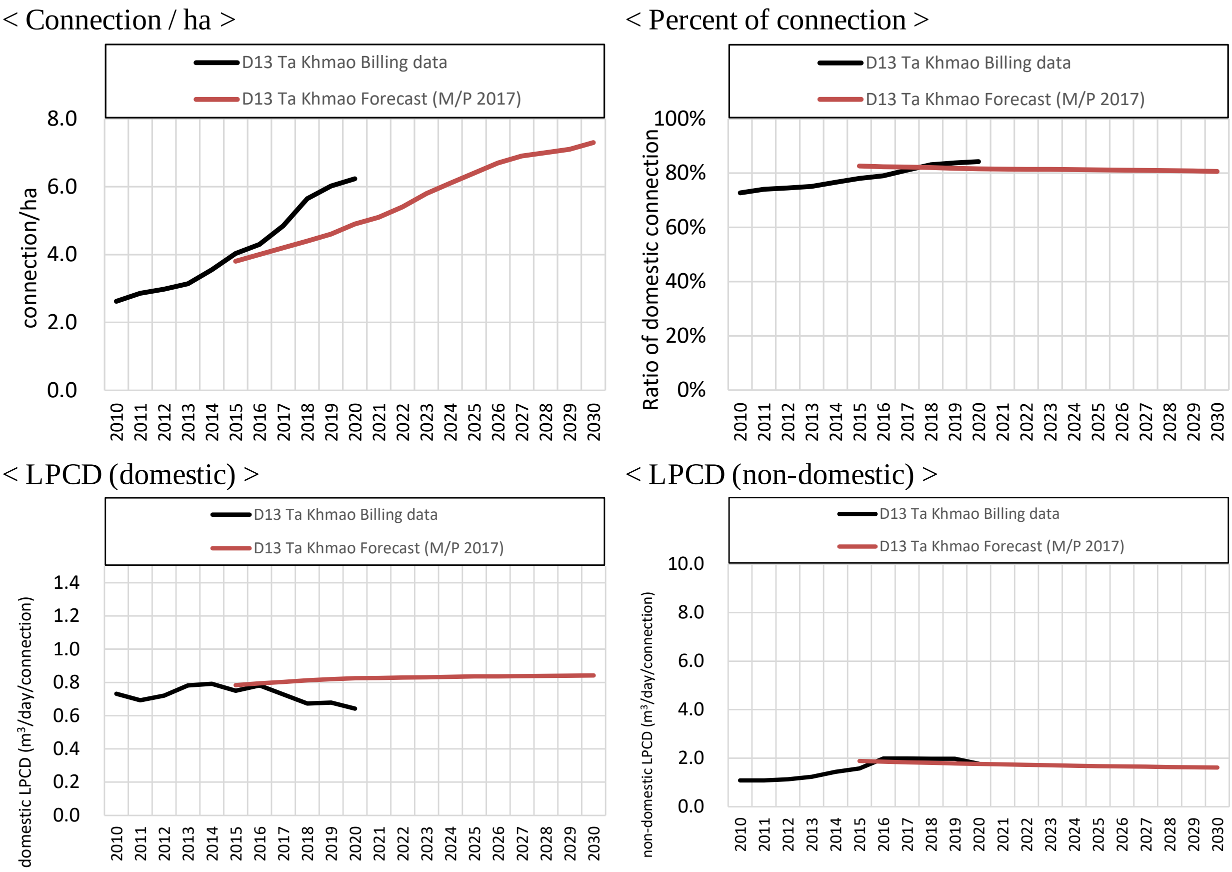


Figure 3.2-14 Comparisons of Water Demand Forecast and Billing Data (Khan Ta Khmao)
Source: JICA Data Collection Survey Team based on billing data and M/P 2017

According to the comparisons between the water demand forecast of the Third Master Plan (M/P 2017) and billing data at the Khan level, the following characteristics were observed:

- Khans with Sangkats with a small number of connections tend to show difference between the billing data and forecasts by the Third Master Plan (M/P 2017).
- Khans that do not have Sangkats with a small number of connections tend to have better forecasts.

(3) Comparisons by the Entire Area

The comparisons by the entire area are shown in ***Figure 3.2-15***.

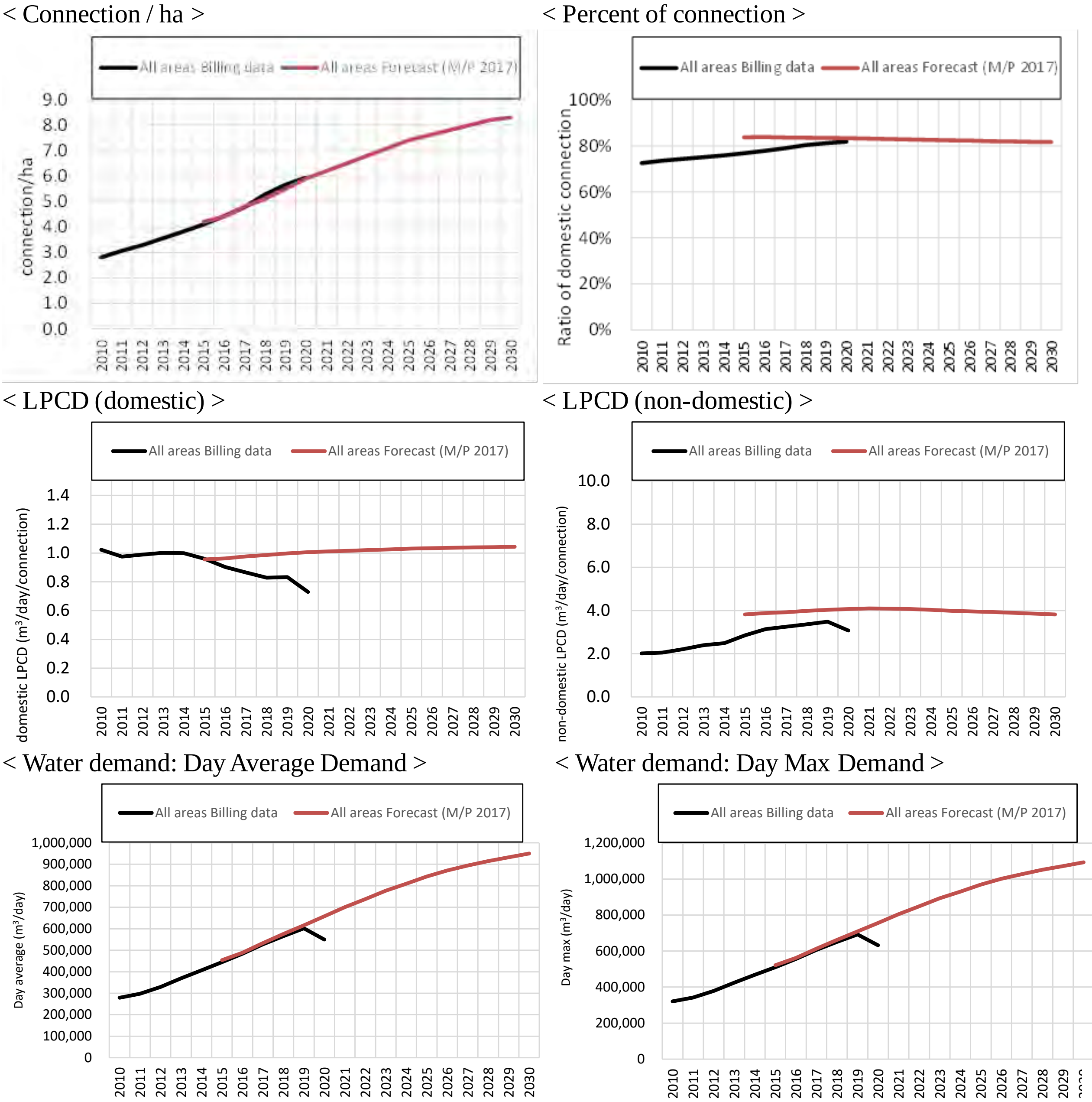


Figure 3.2-15 Comparisons of Water Demand Forecast and Billing Data (Entire Area)

Source: Prepared by JST based on billing data and M/P 2017

According to the comparisons between the water demand forecast of the Third Master Plan (M/P 2017) and billing data of the entire area, the following characteristics were observed:

- Some items such as the number of connections and LPCD are different between the water demand forecast of the Third Master Plan (M/P 2017) and billing data.
- Other items are similar between the water demand forecast of the Third Master Plan (M/P 2017) and billing data.

Although most of the items are almost the same between the water demand forecast of the Third Master Plan (M/P 2017) and billing data, actual situation is different from the following reasons:

- As shown in "**3.2.1(2) Water Production**", all of the WTPs are operating under overload conditions in recent years.

- If the capacity of the existing WTPs was sufficient, the amount of water supplied should be increase.
- There is unmet water demand, which cannot be billed for because the water was never treated or consumed.
- Therefore, the water demand forecast of the Third Master Plan (M/P 2017) should be higher than the current forecast.

From the above reasons, it is evaluated that the water demand forecast of the Third Master Plan (M/P 2017) underestimates the water demand.

(4) Summary of Comparison Between Water Demand Forecast of the Third Master Plan (M/P 2017) and Billing Data

Summary of comparison between water demand forecast of the Third Master Plan (M/P 2017) and billing data is shown in ***Table 3.2.6***.

Table 3.2.6 Summary of comparison water demand forecast of the Third Master Plan (M/P 2017) and billing data

ITEM	CONTENTS
Sangkat	- In the case of Sangkats with a large number of connections, forecasts tend to be reliable due to clear trends based on the large number of samples. - In the case of Sangkats with a small number of connections, forecasts tend to be unreliable due to unclear trends based on the small number of samples.
Khan	- Khans that include Sangkats with small numbers of connections tend to show slight differences between the billing data and forecast by M/P 2017. - Khans that do not have Sangkats with small numbers of connections tend to have better forecast.
Entire area	- Some items such as number of connections and LPCD are bit different between the water demand forecast of the Third Master Plan (M/P 2017) and billing data. - Other items are mostly accurate between the water demand forecast of the Third Master Plan (M/P 2017) and billing data. - In terms of lack of the WTPs' capacity, billing data does not show the actual water demand. Therefore, the water demand forecast should be higher than the current forecast by M/P 2017.

Source: JICA Data Collection Survey Team

3.2.4 Evaluation of Water Demand Forecast of the Third Master Plan (M/P 2017)

From the above review, the water demand forecast of the Third Master Plan (M/P 2017) is evaluated as follows.

- The water demand forecast of the Third Master Plan (M/P 2017), which target year is set as 2030, underestimates the water demand from the following reasons.
  - As shown in "**3.2.1(2) Water Production**", all of the WTPs are operating under overload conditions in recent years.
  - If the capacity of the existing WTPs was sufficient, the amount of water supplied should be increased.
  - There is unmet water demand, which cannot be billed for because the water was never treated or consumed.
  - Therefore, the water demand forecast of the Third Master Plan (M/P 2017) should be higher than the current forecast.
- The reasons of the underestimation are coming from the following reasons.
  - The water demand forecast was carried out for each Sangkat.
  - In the case of Sangkats with a small number of connections, forecasts tend to be unreliable due to unclear trends based on the small number of samples.
  - There were Sangkats with a small number of connections. The forecast of those Sangkats was underestimated. As the result of those underestimations, the entire forecast also underestimated the water demand.

3.3 WATER RESOURCES

3.3.1 Water Source Options

In order to secure an additional 400,000 to 500,000 m^3/day water production in Phnom Penh by 2030, eastern, western, and groundwater resources were investigated, keeping in mind sustainability and economic efficiency. Four rivers, the Mekong, Sap, Bassac and Prek Thnot, were included in the investigation. Dam stored water was also studied in the Third Master Plan (M/P 2017). These water resource options for Phnom Penh Capital were evaluated from the viewpoint of geographical conditions, water quantity, and water quality.

(1) Eastern Resources

The Mekong, Sap, and Bassac Rivers were recognized as parts of the eastern resources of water supply, which are abundant and suitable for drinking water production. Four water treatment plants are located in the eastern part of the Phnom Penh Capital.

- Upstream Mekong River (Chroy Changvar WTP)
- Downstream Mekong River (Nirodh WTP)
- Sap River (Phum Prek WTP)
- Bassac River (Chamcar Mon WTP)

At the time of the Third Master Plan (M/P 2017), the eastern resources had sufficient capacity to cover the overall needs of Phnom Penh until 2030 and beyond. The totality of water needs of Phnom Penh (1,000,000 m^3/day) represented only 0.44% of the minimum Mekong flow, 0.08% of the average flow and 0.03% of the maximum flow. River water was reliably good in quality, particularly the Mekong, and suitable for drinking water production.

Impact of hydropower dams planned for construction upstream on the Mekong River, as well as climate change, were investigated by the Mekong River Commission (hereinafter, MRC) and the conclusions are shown in ***Table 3.3.1*** and ***Table 3.3.2***, respectively. Dams may affect hydrology and sediment transport, and lead to instability of riverbanks. However, that does not significantly impact the quantity or quality of the resource for drinking water production. No updates on quantitative investigation of these impacts are not implemented and reported by MRC.

According to the latest documents related to impacts of hydropower dams and climate change (MRC, 2019), their impacts were found to be similar to previous studies and have no changes on the qualitative or quantitative investigation. It is not necessary to make a major update to the impacts estimated in the Third Master Plan (M/P 2017).

Table 3.3.1 Summary of Impacts on Hydrology and Sediment Transport due to Mekong Dams

CATEGORY	IMPACT
Flow power	✓ Reduction by between 10-30% of the peak flow power. ✓ Lower efficiency of geomorphologic processes (sediment transportation, seasonal cycles in deep pools and flushing of sediments out into the marine environments).
Water surface level changes	✓ Decrease of maximum levels and increase of minimum levels (see ***Figure 3.3-1***). ✓ Rapid fluctuations in water levels increase in magnitude depending on dam operation and effectiveness of a regulating structure downstream of China dams. ✓ Loss of 300,000 ha of flooded area (the majority of which being areas with flood depths greater than 3m). ✓ Reduction of the Tonle Sap Lake area by 5-10% during the seasonal flood. ✓ Reduction of the hydraulic gradient driving flow in and out of the Tonle Sap. ✓ +5 to +8 % increase of dry season area of the lake. ✓ -3 to -5 % reduction of wet season area of the lake. ✓ No conclusion about the impacts on flood levels.
Sediment transport	✓ Reduction of coarse sized sediment loads and increase of erosion of medium-sized sediments currently stored within the riverbed banks. ✓ Bank instability may take 15 to 30 years between Kratie and Phnom Penh. ✓ 20% reduction of fine sized sediment load in the Upper Mekong Basin, and half in the downstream of Kratie.

Source: Third Master Plan (M/P 2017) (based on the MRC report, 2010)

Table 3.3.2 Summary of Impacts on Hydrology due to Climate Change

CATEGORY	IMPACT
Annual rainfall	From 15% to 21% increase
River flow	From 9% to 22% increase
Extreme events	Increase of the incidence and duration
Water level	Unknown

Source: Third Master Plan (M/P 2017) (based on the MRC report, 2010)

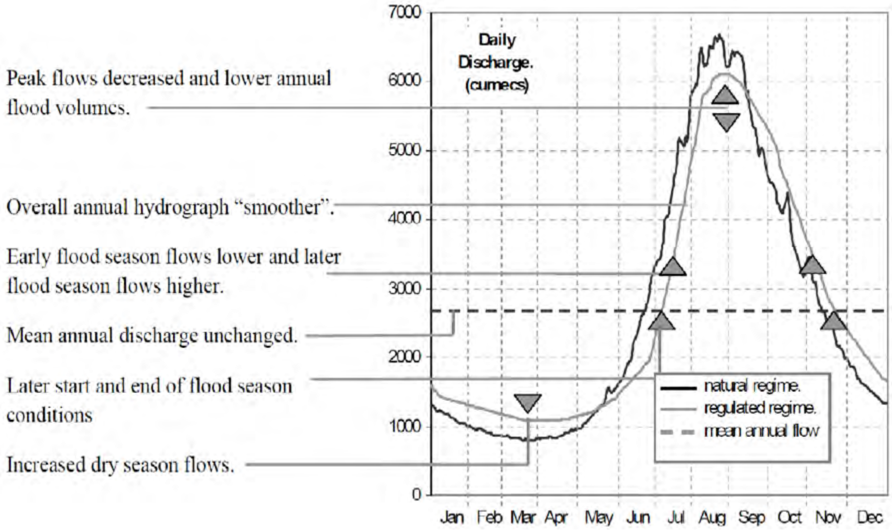


Figure 3.3-1 General Characteristics of the Mekong Hydrograph from the Upstream Mekon River and Tributary Storage Hydropower

Source: MRC, 2010

(2) Western Resources

Western Resources, especially in the Prek Thnot River basin, were investigated. The investigation found limited development potential. The basin will probably not provide more than 50,000 m^3/day. A water balance between the Prek Thnot River flow and the various user requirements (mainly irrigation) showed a shortage of water from January to April of up to 1.3 m^3/s.

According to river flow investigations at the time, flows in the Prek Thnot River in the lower catchment showed great variability between the dry and wet seasons. In the dry season, flows regularly stayed under 3-4 m^3/s and sometimes fell below 1 m^3/s. No change was witnessed in this trend until 2020 after development of the Third Master Plan (M/P 2017).

On the other hand, if water demand of Phnom Penh keeps increasing faster than expected, that resource could provide significant relief. A water supply potential of dams upstream were also investigated. Dams located in the western area, including potential locations for dam construction, were identified, and evaluated for possibility of water supply and conveyance to the possible location of water treatment plant, as shown in ***Figure 3.3-2***. As indicated in ***Table 3.3.3***, two dam locations have significant potential based on the analysed criteria.

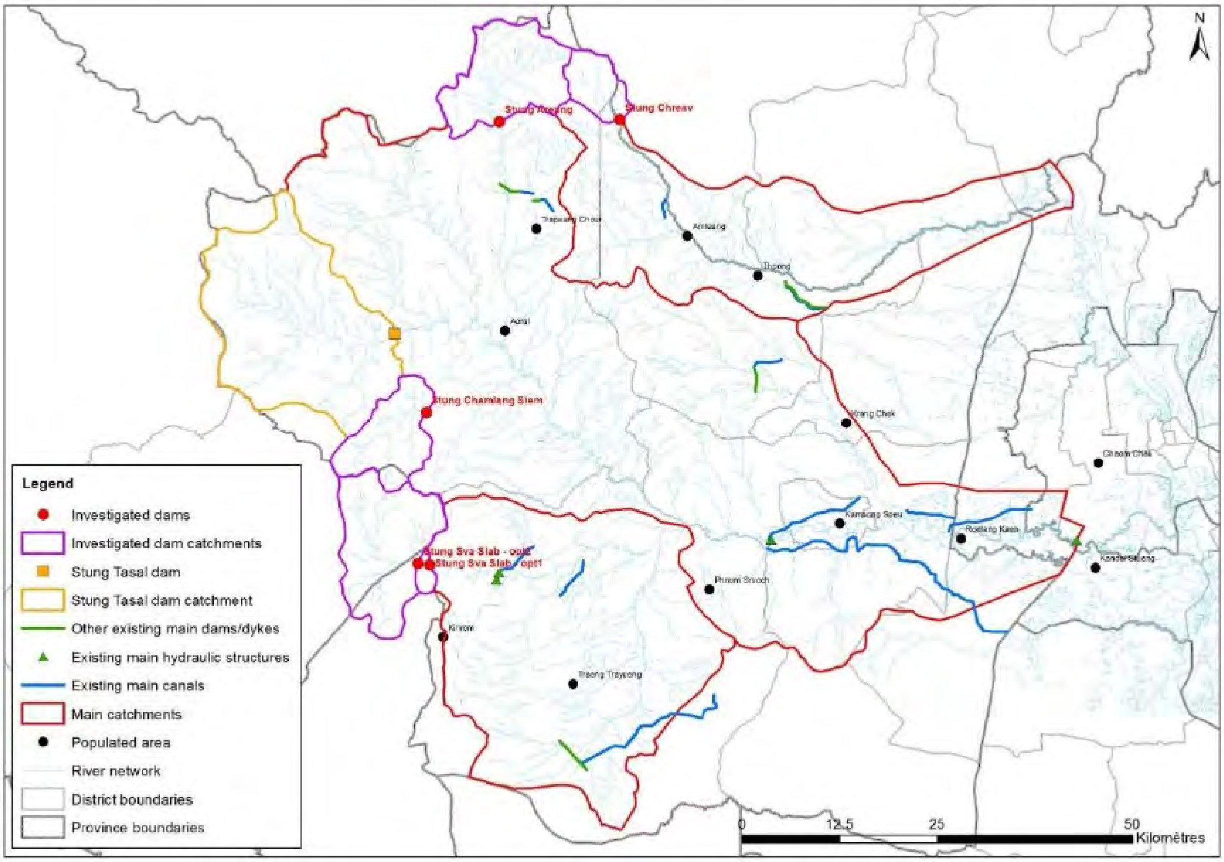


Figure 3.3-2 Existing and Possible Dams Locations Investigated in the Third Master Plan
Source: Third Master Plan (M/P 2017)

Table 3.3.3 Evaluation Results of Potential Source

POTENTIAL SOURCE	STATUS	EVALUATION RESULTS
Stung Tasal Dam	Existing (Indian Government)	Already allocated to irrigation requirements and no chance to provide for others
Stung Chreav	Found and investigated in the Third Master Plan (M/P 2017)	Difficult to achieve (because there is a risk that the dam reservoir will not be full during the rainy season in a drought year, and sustainable water supply will be difficult)
Stung Areang	Dam construction plan exists (study carried out by KOICA)	More potential
Stung Chamlang Sien	Found and investigated in the Third Master Plan (M/P 2017)	Difficult to achieve (because pumping is required between the dam reservoir and water treatment plant, which is inefficient)
Stung Sva Slab 1	Found and investigated in the Third Master Plan (M/P 2017)	Difficult to achieve (because the reservoir storage will be insufficient due to water supply to treatment plant and the required amount of water supply may not be secured)
Stung Sva Slab 2	Submitted the construction project (Indian Government)	More potential and best location analysed

Legend: KOICA (Korea International Cooperation Agency)
Source: Third Master Plan (M/P 2017)

However, it would be quite difficult to utilize these dam resources in the short to medium term, as described in the two points below. The Third Master Plan (M/P 2017) suggested PPWSA continue to negotiate for water allocation for urban water supply with the relevant authorities (in particular, MOWRAM in charge of water resources) or water users, from a long-term view.

- ✓ There is no room to supply water for WTP(s) of PPWSA, since water in the existing dam has already been allocated completely. Moreover, the purpose of the dam planned for construction is agricultural irrigation only.
- ✓ Dam construction is not under PPWSA purview. Negotiations for construction of a multi-purpose dam would be a long-term process.

(3) Groundwater Resource

Groundwater resources were investigated, and it was concluded that there is no potential for water supply based on the investigation in the Second Master Plan (M/P 2006). Groundwater resource characteristics in the suburbs of Phnom Penh Capital showed that shallow wells dry up in the dry season whereas deep wells produce water having high iron content. (See ***Table 3.3.4***)

The average safe pumping yield (26 l/min) corresponded to 1.6 m^3/hr or 37 m^3/day as shown ***Table 3.3.5***. It would be necessary to create several thousand wells for providing significant amounts of water. This is considered impossible because the draw off caused by such a multitude of wells would decrease the productivity of each. Groundwater is still not selected as a water resource, same as in the Third Master Plan (M/P 2017).

Table 3.3.4 Groundwater Characteristics

GROUNDWATER WELL TYPE	WELL DEPTH (DIAMETER)	AQUIFER TYPE	GEOLOGY	WATER QUALITY
Shallow hand-dug	< 7m (1-1.5m)	Unconfined (dried up in dry season)	Silt & clay	Organic contamination, High Cl, TDS
Shallow tubular	< 30m (10-15cm)	Unconfined /Confined	Silt & clay, Sand & gravel	Less contamination, High Fe, Cl, TDS
Deep tubular	> 30m	Confined	Silt & clay, Sand & gravel	High Fe
Deep tubular	> 30m (10-15cm)	Confined	Sand & gravel, Weathered/Crushed zone	High Fe

Source: Third Master Plan (M/P 2017)

Table 3.3.5 Pumping Yields Observed in Phnom Penh

AQUIFER	NUMBER OF WELLS	STATIC WATER LEVEL		SAFE PUMPING YIELD (L/MIN)		
		DRY SEASON	WET SEASON	AVERAGE	MAXIMUM	MINIMUM
Alluvial	48	12.12	11.86	20	40	8
Alluvial with Fissure	26	8.47	5.56	28	103	10
Fissure	91	9.38	7.66	29	210	8
Average in total	165	9.90	8.80	26	210	8

Source: Third Master Plan (M/P 2017)

3.3.2 Choice of Water Source for Future Development

The Third Master Plan (M/P 2017) concluded that PPWSA should continue to rely on the eastern resources to secure 400,000 – 500,000 m^3/day to fulfill future water demand. The downstream part of the Mekong River around Phnom Penh has already been mobilized by Nirodh WTP, which represents almost half of PPWSA's water production capacity. There was no obvious site available for additional water production and water transport capacity has been already saturated by the existing transmission mains. Since urban development and related water consumption are increasing the north of the city, a large-scale water production facility using the Sap or Mekong River as a raw water resource should be considered in the north area.

The location of the water intake and water treatment plant proposed in the northern area (left bank of the Sap River and right bank of the Mekong River) is indicated in ***Figure 3.3-3***. The Sap River and Mekong River locations were compared from the viewpoints of the items listed in ***Table 3.3.6***.

Figure 3.3-3 Location of Mekong and Sap Resources Investigated in the third Master Plan
Source: Third Master Plan (M/P 2017)

Table 3.3.6 Summary of Choice of Water Source

CATEGORY	EVALUATION ITEM	TONLE SAP RIVER	MEKONG RIVER
Water quantity and quality	Quantity of raw water	Good	Excellent
	Quality of raw water	Fair	Good
	Complexity of treatment	Fair	Good
	Perspectives on water quality evolution	Poor	Good
Geographical	Location	Fair	Poor
	Population	Low	Low
	River crossing	Tonle Sap	Tonle Sap
Cost	Additional costs due to treatment	$13.2M	-
	Additional costs due to pipes	-	$24.7M
	Land price	$30M	$15M
	Cost difference	+$3.5M	

Source: Third Master Plan (M/P 2017)

Four categories of characteristics, such as physical, mineral, chemical, and bacteriological factors, were compared, as indicated in ***Table 3.3.7***. These parameters were dominating factor on the water treatment, and resources were evaluated by these parameters based on the actual monitoring results. The Sap River had sufficient quantity to meet water demands all through the year. However, the Sap River had a low rating in quality due to urban wastewater disposal and stormwater runoff of polluted soils.

Table 3.3.7 Comparison of Mekong and Sap Water Quality

		Overall		Dry season		Rainy season	
		Mekong	Tonle Sap	Mekong	Tonle Sap	Mekong	Tonle Sap
Physical	Temperature	28.7 (22.4 - 32.6)	28.8 (23.8 - 32.8)	28.4	28.6	29.1	29
	pH	7.8 (6.8 - 8.6) *[increasing trend]*	7.2 (6.6 - 8.4)	8	7.1	7.6	7.3
	Turbidity	113 (9 - 913)	111 (8 - 1003)	32	78	205	150
	DO	6.8 (4 - 9.4)	5.3 (0.7 - 8.1)	7.2	4.9	6.4	5.8
	Colour	26 (0 - 132)	43 (5 - 264)	10	42	45	44
Mineral	Conductivity	148 (60 - 226)	106 (61 - 233)	170	92	121	123
	Total hardness	60 (24 - 96)	40 (16 - 88)	69	33	51	48
	Mg hardness	19 (3 - 56)	14 (4 - 36)	21	13	16	14
Chemical	Organic matter	10 (0.8 - 57)	18 (4 - 42) *[increasing trend]*	7	21	14	16
	Ammonia	0.13 (0 - 0.48)	0.37 (0 - 1.63)				
	Iron	0.26 (0 - 3.4) *[increasing trend]*	0.6 (0 - 6.4) *[increasing trend]*				
	Manganese	0.02 (0 - 0.2?)	0.03 (0 - 0.12)				
Bacterio	Faecal Coliforms	7.10^2 $(0 - 3.10^4)$	7.10^3 $(20 - 2.10^5)$	581	4800 *≈1000 at intake site*	755	9800 *≈ 13 000 at intake site*

*: Blue cell indicates similar characteristics, green/red cell indicates which resource is more/less favorable for water treatment.
Source: Third Master Plan (M/P 2017)

Results of evaluation were as follows:

- ✓ The Mekong River has good quality and is a more favorable resource for water production. During dry season, pH allows proper flocculation, turbidity is low, oxygenation is rather good, and the bacteriological content is low.
- ✓ The Sap River has its worst quality during the dry season. pH is low and mineralization lower than Mekong, which is problematic for treatment; organic content is higher and fecal coliforms content is 10 times as much as in the Mekong.
- ✓ During the wet season, both resources are very similar (Mekong water flows into the Sap River). Only differences are bacteriological content is much higher in the Sap than in the Mekong.
- ✓ Both resources show a low level of chemical contamination.
- ✓ The construction of a wastewater treatment plant was proposed in the north of Phnom Penh along Sap River and the effluent would be released in the Sap River. There is high uncertainty about the treatment standards and effluent quality. It could heavily impact the Sap water quality in the medium to long term.

It will be necessary to evaluate future impact of each water resource by considering urban drainage or sewage system plans. Regarding this point, the possibility of impact on water quality is described in **Section 5-2-3**.

Furthermore, preliminary evaluation on costs was implemented. For the Sap River water, an additional pre-ozonation step was considered. On the other hand, for the Mekong resource, the site was located further away requiring a longer treated water transmission main. In addition, land price also was estimated for each resource. As the results, the Sap option was $3.5M more expensive than the Mekong resource. It was shown that the difference in land price will be major driver in the option evaluation.

Based on these proposals on choice of water resource, the Bakheng WTP and intake, located in the north area of Phnom Penh Capital, is under construction, with financial support from AfD.

The current water source assessment is discussed in **Chapter 5**, however the Mekong River remains the best water source in terms of water quantity, quality and additional costs associated with location.

Considering efficiency, economy, and time constraints, it is appropriate to exclude from the candidates the dam reservoir of groundwater and western water sources. The evaluation results were appropriate in M/P 2017, which requires securing a water source in a relatively short period.

3.4 Water Production Facilities

3.4.1 Intake

The Third Master Plan (M/P 2017) does not specifically mention existing water intake facilities. On the other hand, future water source candidates are evaluated from the viewpoint of geographical conditions and water quality risk.

3.4.2 Water Treatment Plant

(1) Development after the Third Master Plan (M/P 2017)

The existing water treatment plants as of March 2021 are summarized in ***Table 3.4.1***.

Table 3.4.1 Existing Water Treatment Plants

WTP	PHASE	COMPLETION	DESIGN CAPACITY	TREATMENT METHOD	CONDITIONS
Phum Prek	Phase I	1965/88/95	100,000 m³/d	Coagulation/ Sedimentation/ Filtration	Aged and deteriorated
	Phase II	2003	50,000 m³/d		Partially aged and deteriorated
Chroy Changvar	Phase I	2003	65,000 m³/d		Partially aged and deteriorated
	Phase II	2009	65,000 m³/d		Good
Nirodh	Phase I	2013	130,000 m³/d		Good
	Phase II	2016	130,000 m³/d		Good
Chamcar Mon	---	2019	52,000 m³/d		New and good
		Total	592,000 m³/d		

Source: JICA Study Team based on data provided by PPWSA

Figure 3.4-1 was provided in the Third Master Plan (M/P 2017). It indicates that water production capacity could exceed water demand by completion of Nirodh Phase II WTP.

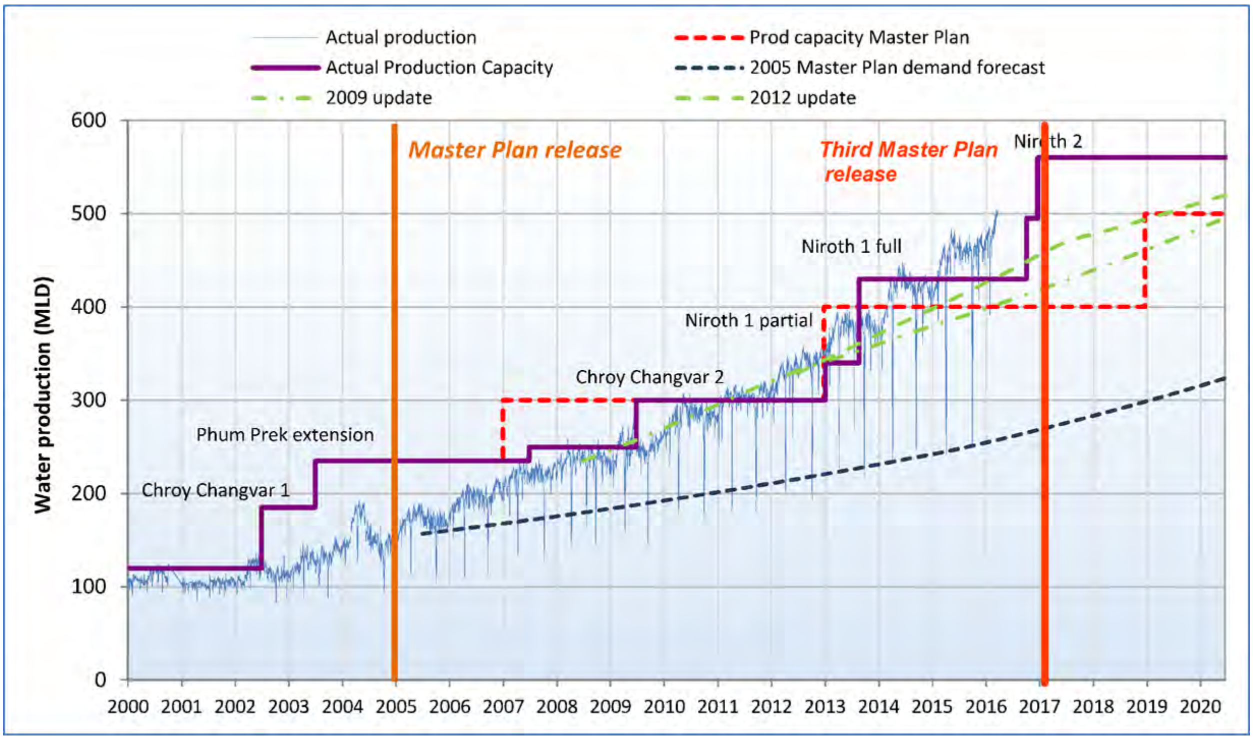


Figure 3.4-1 Actual Water Demand and Production Capacity
Source: Third Master Plan – Period 2016-2030, SAFEGE, (Mar. 2017)

Water demand assumed in the Second Master Plan (M/P 2006) issued in 2005 was greatly exceeded by the actual water demand. The Third Master Plan (M/P 2017) proceeded with the construction of water treatment plants such as Chroy Changver WTP Phase II and Nirodh WTP Phase and Phase II. At the stage of issuing the Third Master Plan in 2017, it was assumed that it would be possible to produce water meeting the water demand estimated in the Third Master Plan (M/P 2017) for the time being. (***Figure 3.4-2***)

Table 3.4.2 Water Teatment Plant Development Plan

Treatment Plant	Construction	Production Capacity (m^3/day)		Completion Date	
		Average	Maximum	Proposed	Present Status
Chamcar Mon	New	52,000	55,000	2019	Completed in 2019
Ta Khmau	New	30,000	-	2021	Under tendering to be completed in 2024
Phum Prek Phase III	Expansion	45,000	-	2026	Under preparation to be completed in 2026
Bakheng Phase I	New	195,000	224,000-	2022	Under construction to be completed in 2023
Bakheng II	Expansion	195,000	224,000-	2024	Under planning to be completed in 2023

Source: JICA Study Tam updated from Third Master Plan, SAFEGE, (Mar. 2017)

However, water demand has sharply increased since 2017, and it had far exceeded the water production capacity of Nirodh Phase II by 2017. Furthermore, capacity expansion of the Chamcar Mon WTP completion at the end of 2019 has not been able to satisfy the growth in water demand, and water shortages continued. Currently, the construction of the new Ta Khmao WTP and the expansion of the Phnom Prek WTP (as Phase III) are behind schedule, while both Bakheng Phase I and Bakheng Phase II projects are expected to be completed in 2023. However, shortages are expected to continue until these three projects are completed.

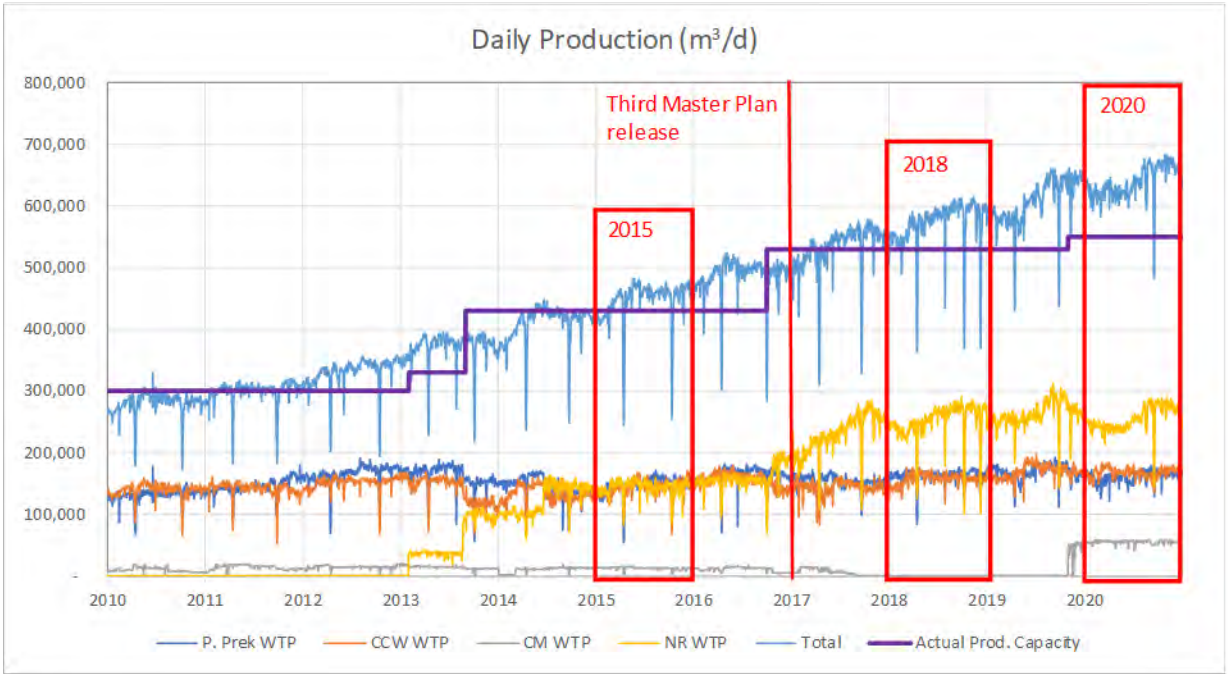
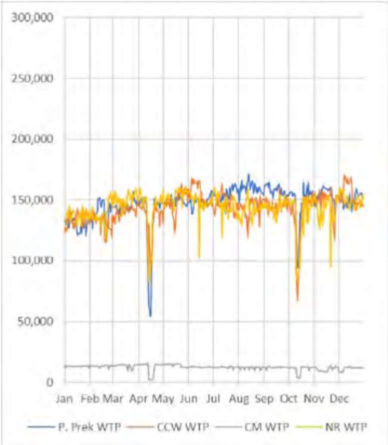


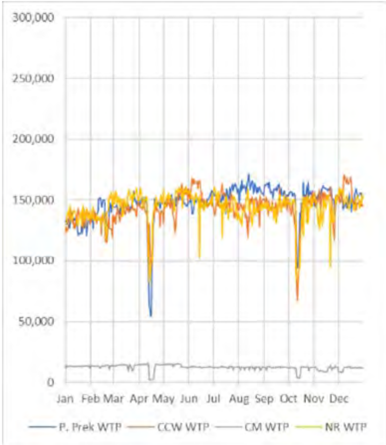
Figure 3.4-2 Actual Water Demand and Production Capacity shown in 2020
Source: JICA Study Team based on data provided by PPWSA

The operating conditions are compared in 2015 before the Third Master Plan (M/P 2017), and in 2018 and 2020 after the Third Master Plan (M/P 2017).

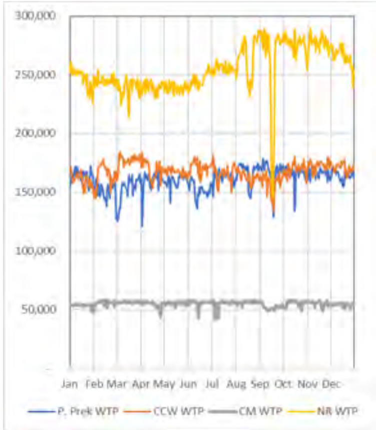
In 2015, four water treatment plants were in operation: Phum Prek, Chroy Changver, Chamcar Mon, and Nirodh WTPs. The Phum Prek, Chroy Changver, and Nirodh WTPs produced about 150,000 m^3/day, and the Chamcar Mon plant produced 12,000 m^3/day. In 2018, operation of the Chamcar Mon WTP was stopped due to the reconstruction work, while the Nirodh WTP completed the second phase of construction and was able to produce 260,000 m^3/day. The Phum Prek and Chroy Changver WTPs exceeded the original capacity and operated at about 160,000 m^3/day. Furthermore, in 2020, reconstruction of the Chamcar Mon WTP was completed and added 55,000 m³/day. However, in order to meet the water demand, the other three WTPs need to continue to operate under overload conditions.



2015 - Daily Production



2018 - Daily Production



2020 - Daily Production

Figure 3.4-3 Production Capacity in 2015/2018/2020
Source: JICA Study Team based on data provided by PPWSA

Then, the water treatment performance is examined from the viewpoint of raw water quality and treated water quality. It shows the monthly average raw water and treated water turbidity from 2010 to 2020.

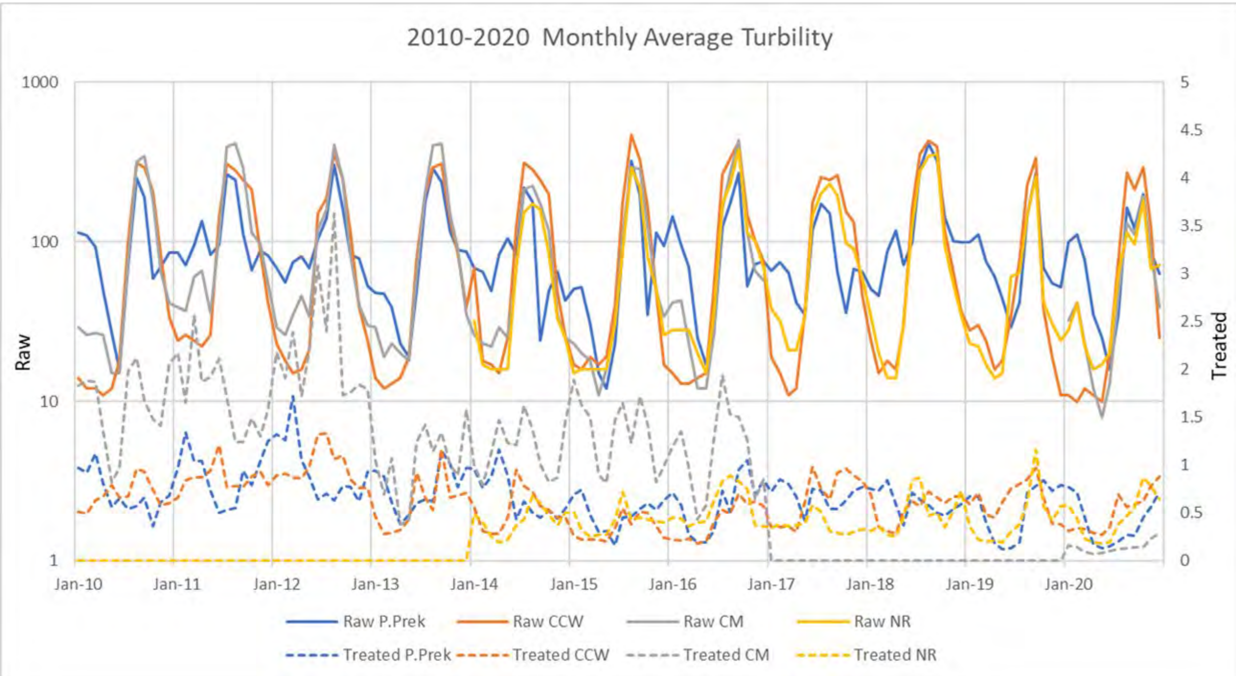
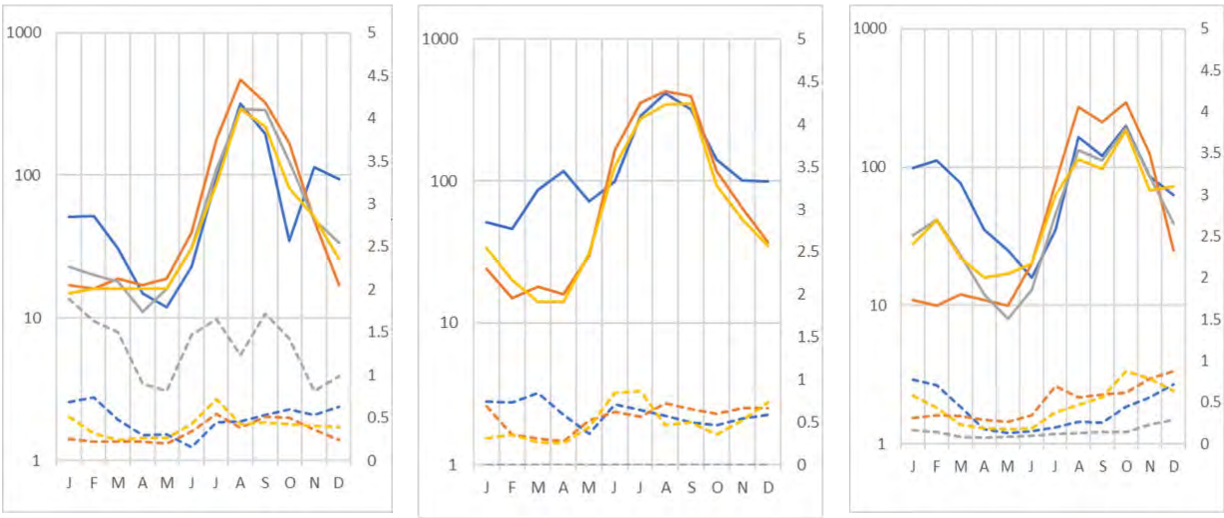


Figure 3.4-4 Raw and Treated Water Turbidity in 2015/2018/2020
Source: JICA Study Team based on data provided by PPWSA

The turbidity of raw water changes regularly due to seasonal changes and fluctuations of the water level of the Mekong River. Treated water turbidity is affected by changes in raw water turbidity, but generally achieves 1 NTU or less.

The raw and treated water turbidity were compared in 2015 before the Third Master Plan (M/P 2017), and in 2018 and 2020 after the Third Master Plan (M/P 2017).



2015 - Raw/Treated Turbidity

2018 - Raw/Treated Turbidity

2020 - Raw/Treated Turbidity

Figure 3.4-5 Production Capacity in 2015/2018/2020

Source: JICA Study Team based on data provided by PPWSA

Raw water turbidity fluctuates in much the same way in each year. On the other hand, treated water has exceeded 1 NTU at the Chamcar Mon WTP in 2015 and has reached nearly 2 NTU. However, after the reconstruction in 2020, the water quality is very good, with turbidities below 0.5 NTU among the four WTPs. All other treated water is also operating well with turbidity below 1 NTU.

(2) Water Treatment Plant Future Development

1) Phum Prek WTP

Phum Prek WTP will be expanded from 150,000 m^3/day to 195,000 m^3/day by 2026, under the Japanese New Grant Aid Scheme with O&M as Phase III. After the expansion of the capacity of the WTP, aged facilities (constructed in Phase I) with a capacity of 100,000 m^3/day and service reservoir with a capacity of 10,000 m^3 are proposed be re-constructed. In addition, the additional sludge treatment facilities are proposed be constructed after the re-construction of Phase I facilities.

2) Bakheng WTP

Bakheng WTP Phase I with a capacity of 195,000 m^3/day targeted in 2023 is under construction.

The construction of Bakheng WTP Phase II will be implemented with an additional capacity of 195,000 m^3/day also targeted in 2023 too, under the AfD financial scheme. Approximately 7 ha of land is available in the existing site for Phase III.

Table 3.4.3 Bakheng WTP Treatment Facilities

ELEMENT		NUMBER / TYPE	CONTENTS	REMARK
Bakheng I	Flow Distribution Chamber	1	395,000 m^3/d	Sized for Bakheng I and II
	Flash Mixer	3*2 series	1-2 min	
	Flocculation Tank	9*2 series	20-30 min	Mechanical type (vane stirrer)
	Sedimentation Tank	9*2 series	64 min	Lamella settling, turbidity<5 NTU
	Rapid Sand Filer	9*2 series	192 m/d (ave.) 220 m/d (max)	Filter area: 64 m^2/each filter Backwash: air and water
	Treated Water Tank	2	22,500 m^3	5.5 hours of the WTP capacity
	Backwash Pumping Station	1		Sized for Bakheng I and II
	Pumping Station	1	395,000 m^3/d	Sized for Bakheng I and II
	Treated Water Pump	6+1	2,600 m^3/h, 69 m	Variable speed
	Coagulant	PAC	12 (max 30) mg/L	
	pH Adjustment	Lime	10 (max 40) mg/L	Probably not applied.
	Pre-chlorination	NaClO	1.5 (max 2.5) mg/L	On-site preparation
	Post-chlorination	NaClO	1 (max 1.5) mg/L	On-site preparation
	Building for Chlorination	1		Sized for Bakheng I and II
	Building for Lime and PAC	1		

ELEMENT		NUMBER / TYPE	CONTENTS	REMARK
Bakheng II	Flow Distribution Chamber	-	-	Constructed during Bakheng I
	Flash Mixer	3*2 series	1-2 min	
	Flocculation Tank	9*2 series	20-30 min	Mechanical type (vane stirrer)
	Sedimentation Tank	9*2 series	64 min	Lamella settling, turbidity<5 NTU
	Rapid Sand Filer	9*2 series	192 m/d (ave.) 220 m/d (max)	Filter area: 64 m^2/each filter Backwash: air and water
	Treated Water Tank	2	22,500 m^3	5.5 hours of the WTP capacity
	Pumping Station	-	-	Constructed during Bakheng I
	Treated Water Pump	6+1	2,600 m^3/h, 69 m	Variable speed
	Coagulant	PAC	12 (max 30) mg/L	
	pH Adjustment	Lime	10 (max 40) mg/L	Probably not applied.
	Pre-chlorination	NaClO	1.5 (max 2.5) mg/L	On-site preparation
	Post-chlorination	NaClO	1 - 1.5 mg/L	On-site preparation
	Building for Chlorination	-	-	Constructed during Bakheng I
	Building for lime and PAC	1		

Source: Third Master Plan – Period 2016-2030, SAFEGE, (Mar. 2017)

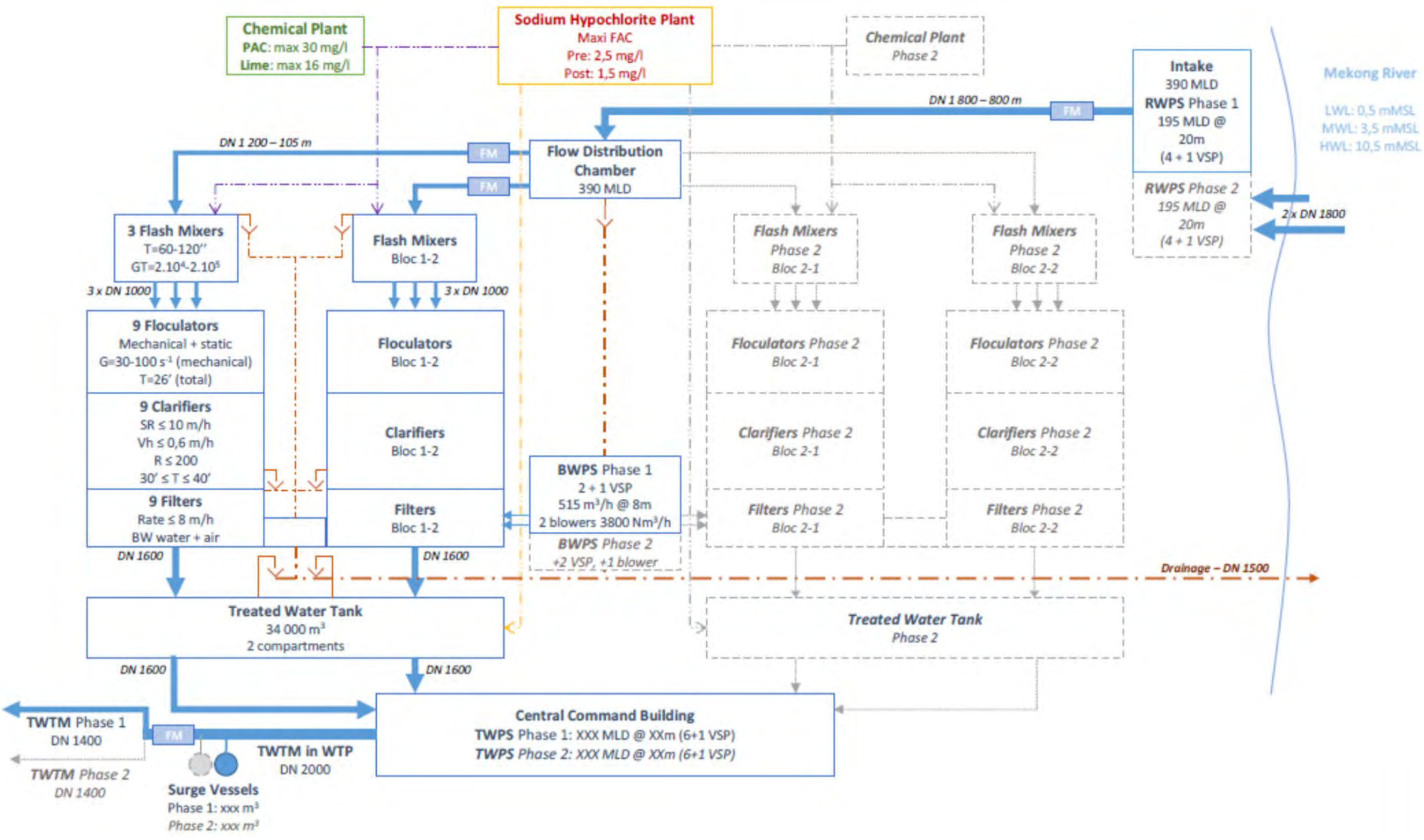


Figure 3.4-6 Production Capacity in 2015/2018/2020
Source: JICA Study Team based on data provided by PPWSA

3) Ta Khmao WTP

Ta Khmao WTP with a capacity of 30,000 m^3/day will be constructed under the Japanese New Grant Aid Scheme with O&M, and the completion of the construction is targeted in 2024. The WTP will be constructed by Design & Build works and final design will be proposed by the Contractor and determined in the Design & Build Stage. The general layout of the facilities and the typical section provided in the preparatory survey implemented by JICA are shown below as references.

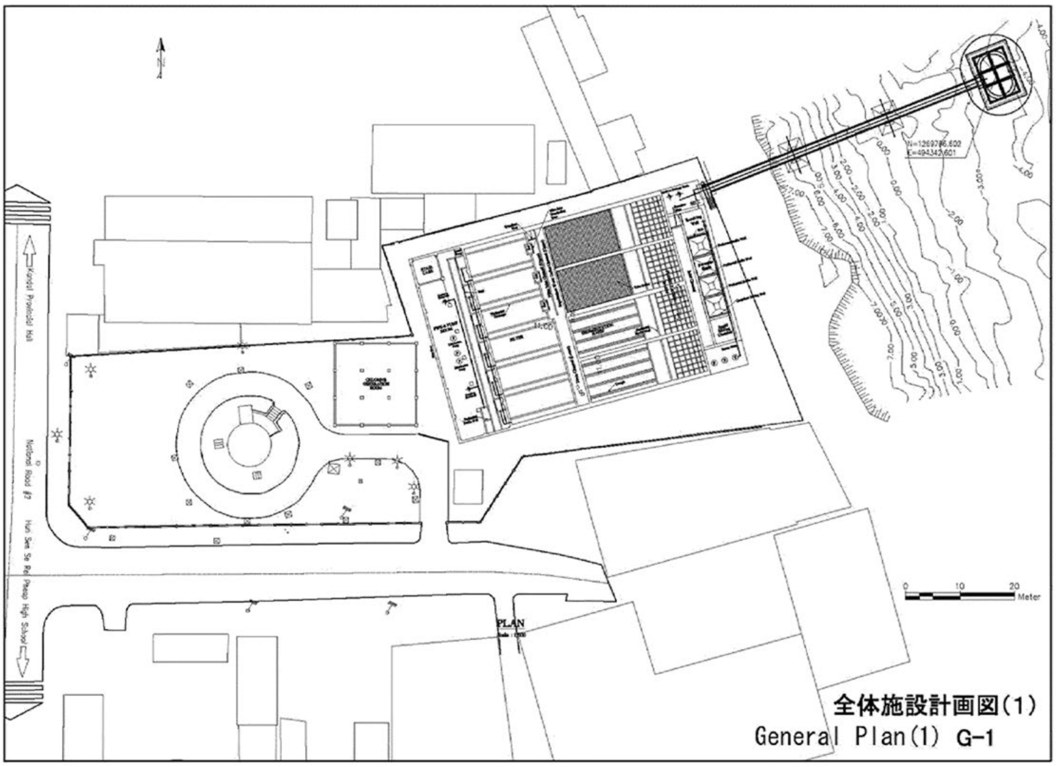


Figure 3.4-7 Water Treatment Plant for Ta Khmao WTP
Source: JICA

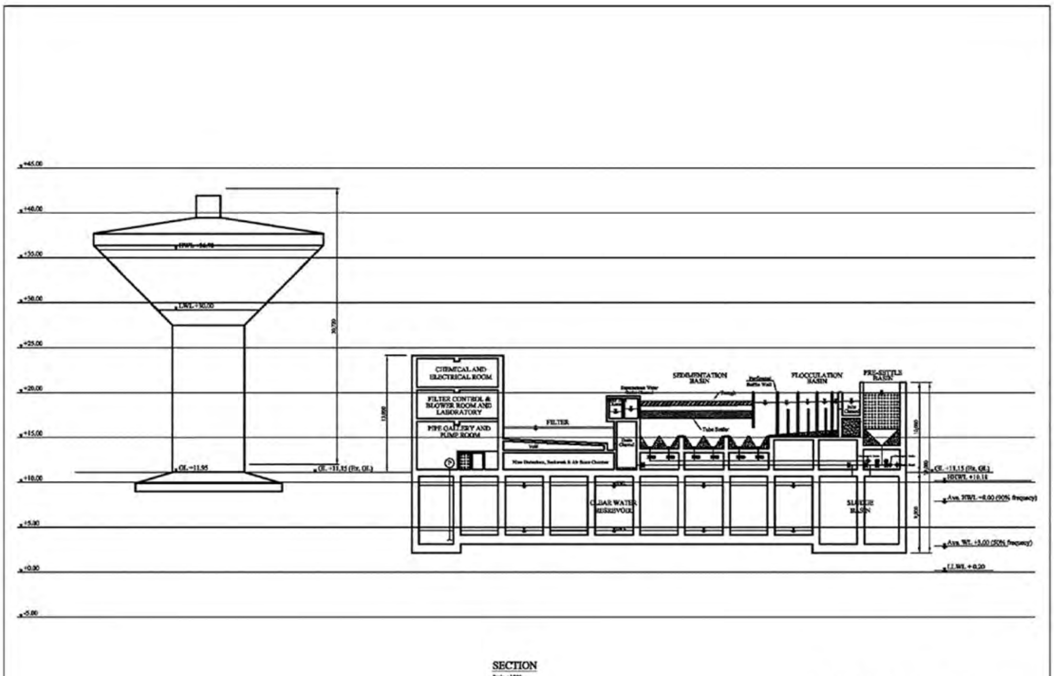


Figure 3.4-8 Water Treatment Process for Ta Khmao WTP
Source: JICA

3.5 Transmission and Distribution Network

3.5.1 Water Transmission

(1) Principles of design

Plans related to the water transmission mains in the Third Master Plan (M/P 2017) include expansion of the pipe network and improvement of existing mains to accommodate the increased water production of the expanded WTPs. In order to adequately respond to the rapid increase of water demand in Phnom Penh, implementation will be phased, as shown in ***Table 3.5.1***.

Table 3.5.1 Principles of Design of Transmission

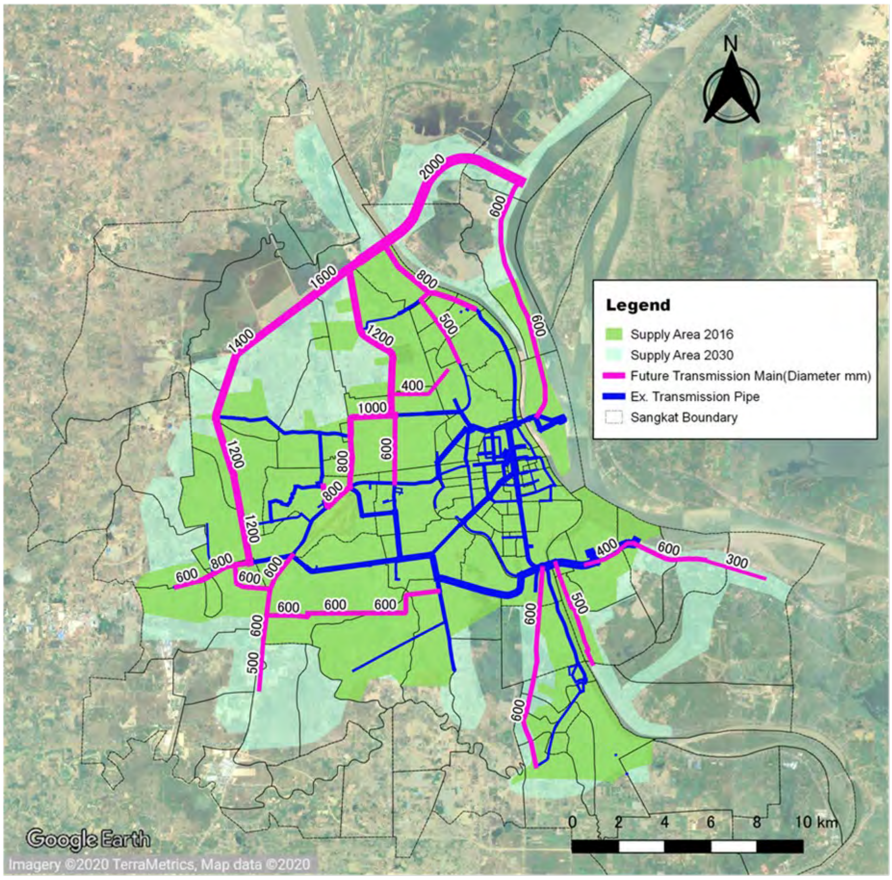
Item	Description
Distribution zones of each WTP	Phase I: Pumped water from the four existing WTPs into the water supply system to increase supply pressure, without defining the distribution zones of each WTP. Phase II: After construction of the Ta Khmao WTP, create an independent distribution zone supplied by Ta Khmao WTP. The existing served area in Phnom Penh Capital will continue to be supplied from other WTPs without re-defining distribution zones. Phase III: After construction of the Bakheng WTP Phase I and II, evaluate looping of the existing transmission mains to increase supply pressure, while continuing to supply water without re-defining distribution zones.
Looping of transmission mains	The Phnom Penh water supply system extends from the south to the east, and from the north to the west. The water supply from Bakheng WTP will be extend from the north to the south. It will be connected to the transmission system to complete the loop of the transmission system.
Defining distribution zones	The distribution zones of each WTP will be managed by establishing District Metered Areas (hereinafter referred to as “DMA”). The arrangement of the DMAs will be considered when planning the layout of the transmission mains.

Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)

The outline of the transmission mains planned according to the principles above is shown in ***Figure 3.5-1***.

In the Third Master Plan (M/P 2017), 106 km of new transmission mains will be installed, in addition to the 113 km already existing.

PPWSA defines water pipes with a diameter of 400 mm or more as transmission mains, and water pipes with diameters of 250 mm, 300 mm, and 350 mm as secondary transmission mains. About 90 km of secondary transmission mains planned. To complete the installation by the target year, 15 km per year will need to be installed.



Diameter (mm)	Length (m)
400	5,800
500	10,300
600	44,200
800	10,400
1,000	2,600
1,200	13,800
1,400	6,700
1,600	2,300
1,800	1,700
2,000	7,900
Total	105,700

Figure 3.5-1 Outline of Transmission Mains
Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)

(2) Phased Development Plan

1) Phasing

The transmission mains will be installed in phases, as shown in ***Table 3.5.2***. The phasing plan will be re-evaluated at the end of each phase to ensure that the plan and the ever-changing conditions on the ground are in alignment.

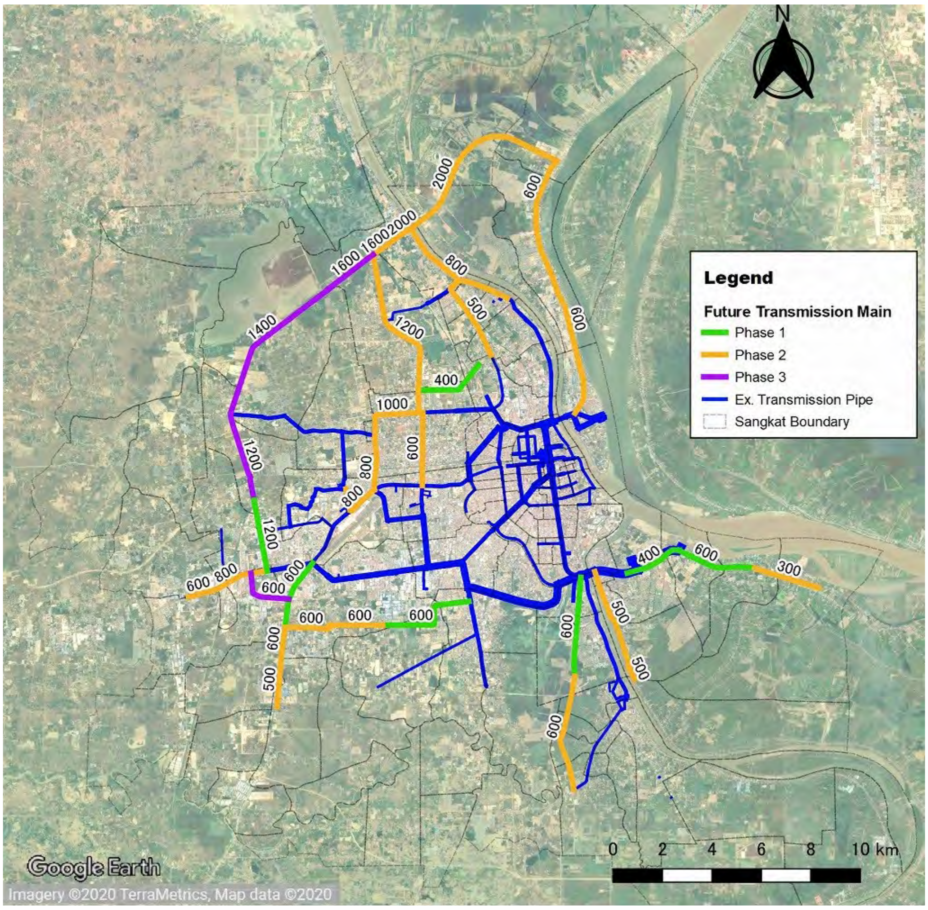
Table 3.5.2 Phasing of Transmission Mains Program

Phase	WTP Expansion Project	
Phase 1	Construction of Chamcar Mon WTP	(2017-2018)
Phase 2	Construction of Bakheng I WTP	(2019-2022)
Phase 3	Construction of Bakheng II WTP	(2023-2024)

Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)

2) Staged Development Plan

The transmission mains shown in ***Figure 3.5-1*** will be installed according to the Phased Implementation Plan that was created based on the Transmission Mains Program shown in ***Table 3.5.2***. The Phased Implementation Plan is summarized in ***Figure 3.5-2***.



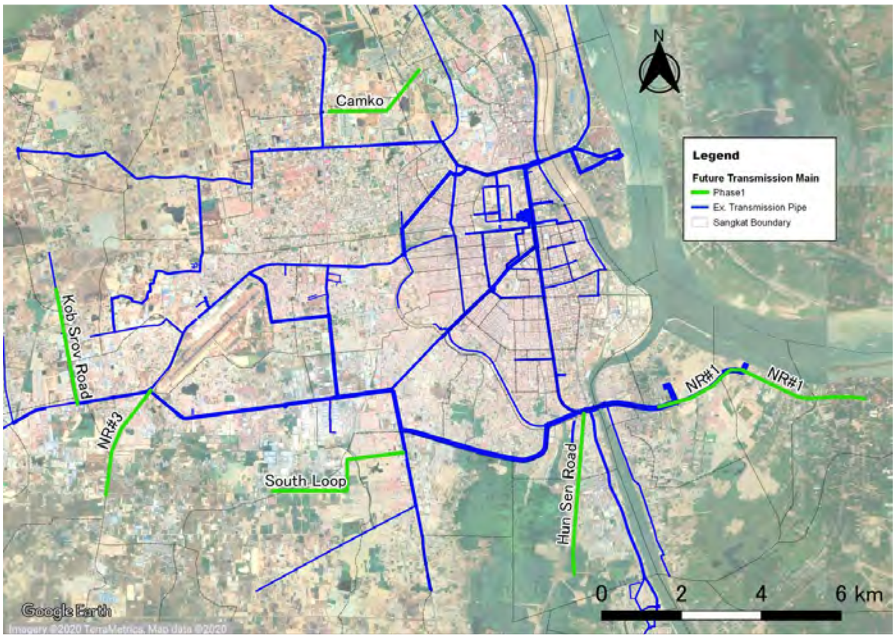
Primary Transmission Mains	
Phase I (2016-2018)	20.9 km
Phase 2 (2019-2022)	69.5 km
Phase 3 (2023-2024)	15.2 km
Total	105.6 km

Secondary Transmission Mains	
Phase 1 Phase 2 Phase 3	15 km of DN 300 mm per year
Total	90 km

Figure 3.5-2 Primary Transmission Mains Program of Phasing
Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)

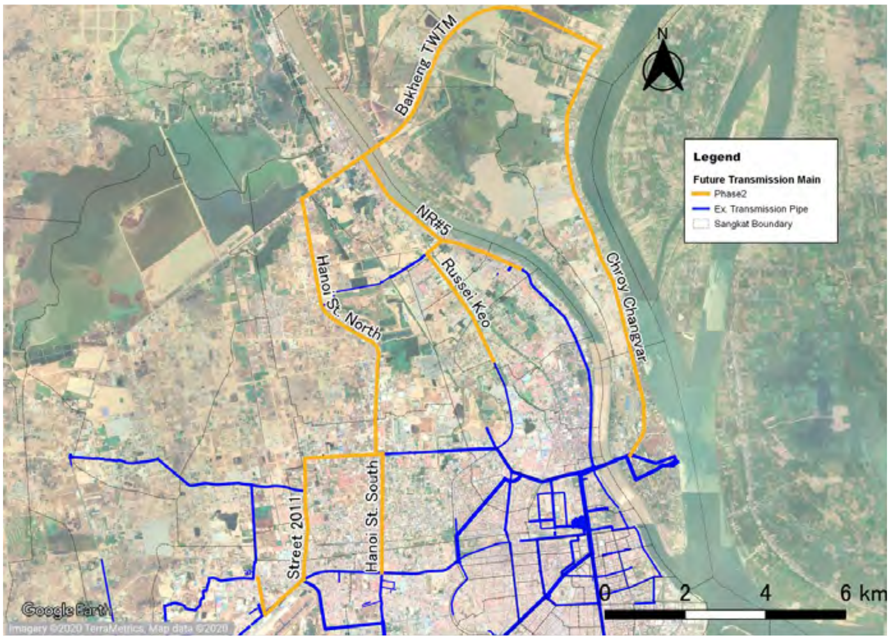
3) Development by Phase

The contents of each phase are shown in ***Figure 3.5-3*** through ***Figure 3.5-6***.



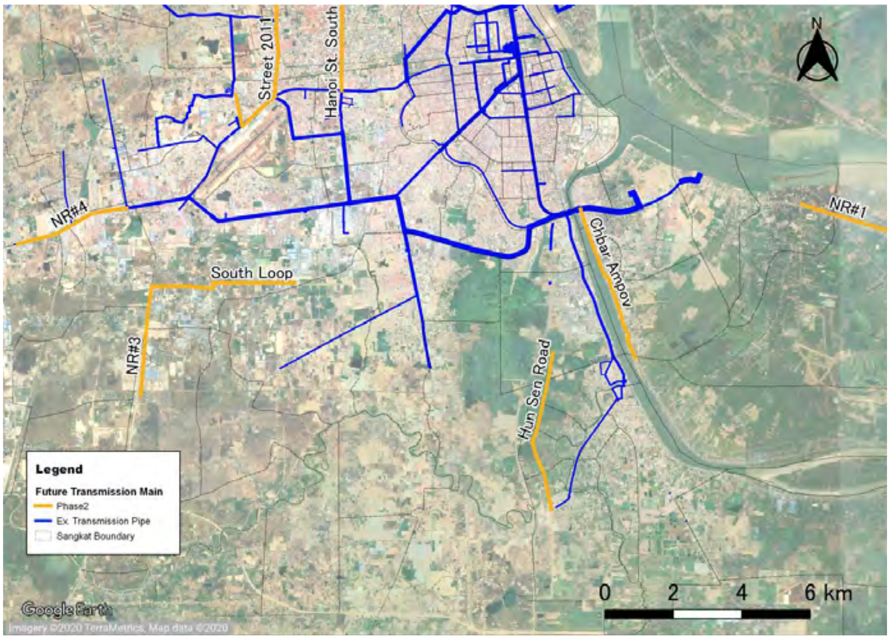
Road	Dia-meter (mm)	Length (m)
Camko	400	1,300
Hun Sen	600	4,100
Kob Srov	1,200	2,900
NR1	600	3,200
NR1	400	2,500
NR3	800	1,200
NR3	600	1,800
South Loop Pipe	600	3,900
	Total	20,900

Figure 3.5-3 Water Transmission Development Policy for Phase 1
Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)



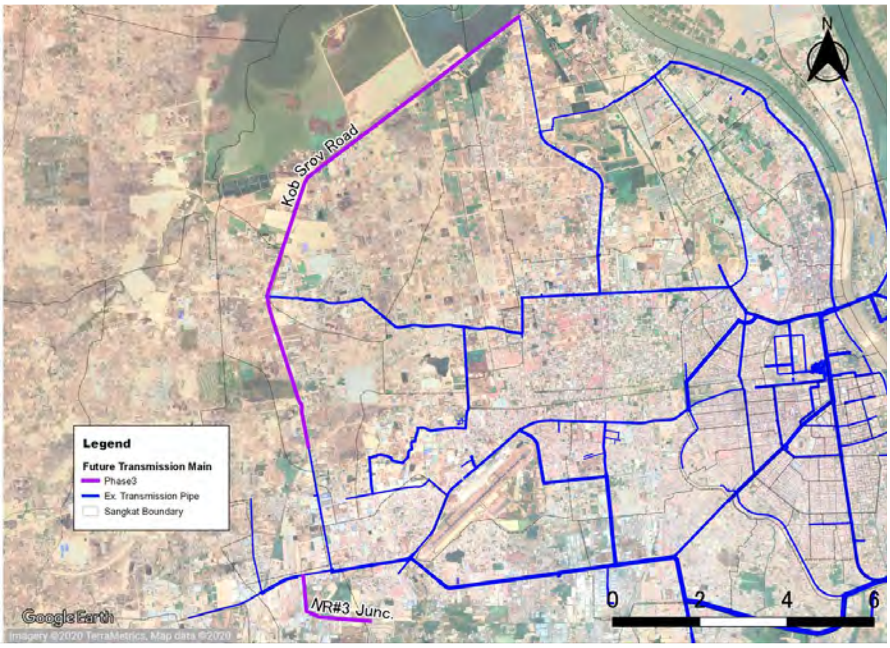
Road	Dia-meter (mm)	Length (m)
Chroy Changvar	600	11,200
Chbar Ampov	500	4,700
St 2011	1,000	1,800
St 2011	800	800
St 2011	600	2,200
Hanoi St North	1,200	7,200
Hanoi St North	800	1,500
Hanoi St North	600	1,400
Hun Sen	600	4,800
Kob Srov	1,800	1,700
NR1	600	2,600

Figure 3.5-4 Transmission Mains Development in Phase 2 (1)
Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)



Road	Dia-meter (mm)	Length (m)
NR3	500	2,000
NR3	400	1,300
NR4	1,000	800
NR4	600	2,700
NR5	800	3,000
NR5	600	1,900
Russei Keo	500	3,600
Russian Blvd	800	1,300
North airport	400	700
South Loop Pipe	600	4,400
TWTM Bakheng	2,000	7,900
	Total	69,500

Figure 3.5-5 Transmission Mains Development in Phase 2 (2)
Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)



Road	Dia-meter (mm)	Length (m)
Kob Srov	1,600	2,300
Kob Srov	1,400	6,700
Kob Srov	1,200	3,700
NR3 Junction	800	2,500
	Total	15,200

Figure 3.5-6 Transmission Mains Development in Phase 3
Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)

(3) Establishment of Distribution Zones

1) Total Head from WTP

Total head expected during each phase from each WTP according to the Third Master Plan (M/P 2017) is shown in ***Table 3.5.3***.

Table 3.5.3 Total Head of Each WTP

WTP	TOTAL HEAD (m AMSL)			
	CURRENT (2017)	PHASE 1 (Construction of Chamcar Mon WTP (2017-2018))	PHASE 2 (Construction of Bakheng I WTP (2019-2022))	PHASE 3 (Construction of Bakheng II WTP (2023-2024))
Bakheng WTP	-	-	62	72
Nirodh WTP	56	60	61	62
Phum Prek WTP	56	56	58	53
Chroy Changvar WTP	61	61	61	56
Chamcar Mon WTP	50	57	58	53
Ta Khmau WTP	-	45	45	45

* m AMSL (Metres above mean sea level)
Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)

In the Third Master Plan (M/P 2017), total head of each WTP was based on the policy of maintaining pressure outlined in ***Table 3.5.3***. Total head was set based on results of network calculations performed on the distribution areas for each phase, and to maintain 1 bar (100 kPa) at the terminus of each distribution area and 3 bar at the terminus of the transmission lines.

2) Distribution Area by Water Treatment Plant

After Phase 3, it will be possible to supply water from Bakheng WTP to the western area of Phnom Penh while maintaining appropriate water pressure. As shown in ***Table 3.5.3***, the pumped pressure of Bakheng WTP and Nirodh WTP will become higher than the other WTPs. To maintain water pressure equilibrium, it is desirable to establish separate distribution areas to be supplied by Bakheng and Nirodh WTPs, and other areas to be supplied by Phum Prek, Chamkar Mon, and Chroy Changyar WTPs. Through such methods, it is possible to modify supply areas and reduce pumping energy requirements.

Distribution areas are summarized in ***Table 3.5.4*** and ***Figure 3.5-7***.

Table 3.5.4 Distribution Area Development Policy

Area	The objectives
A central area supplied by Chroy Changvar, Phum Prek and Chamkar Mon WTPs	This will allow reducing pumping head in the three central WTPs by at least 0.5 bar and therefore energy will be saved. The boundary between both pressure floors can be adjusted according to the demand and production capacity in each area.
A peripheral area supplied only by Nirodh and Bakheng WTPs	Supply to western and south areas

Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)

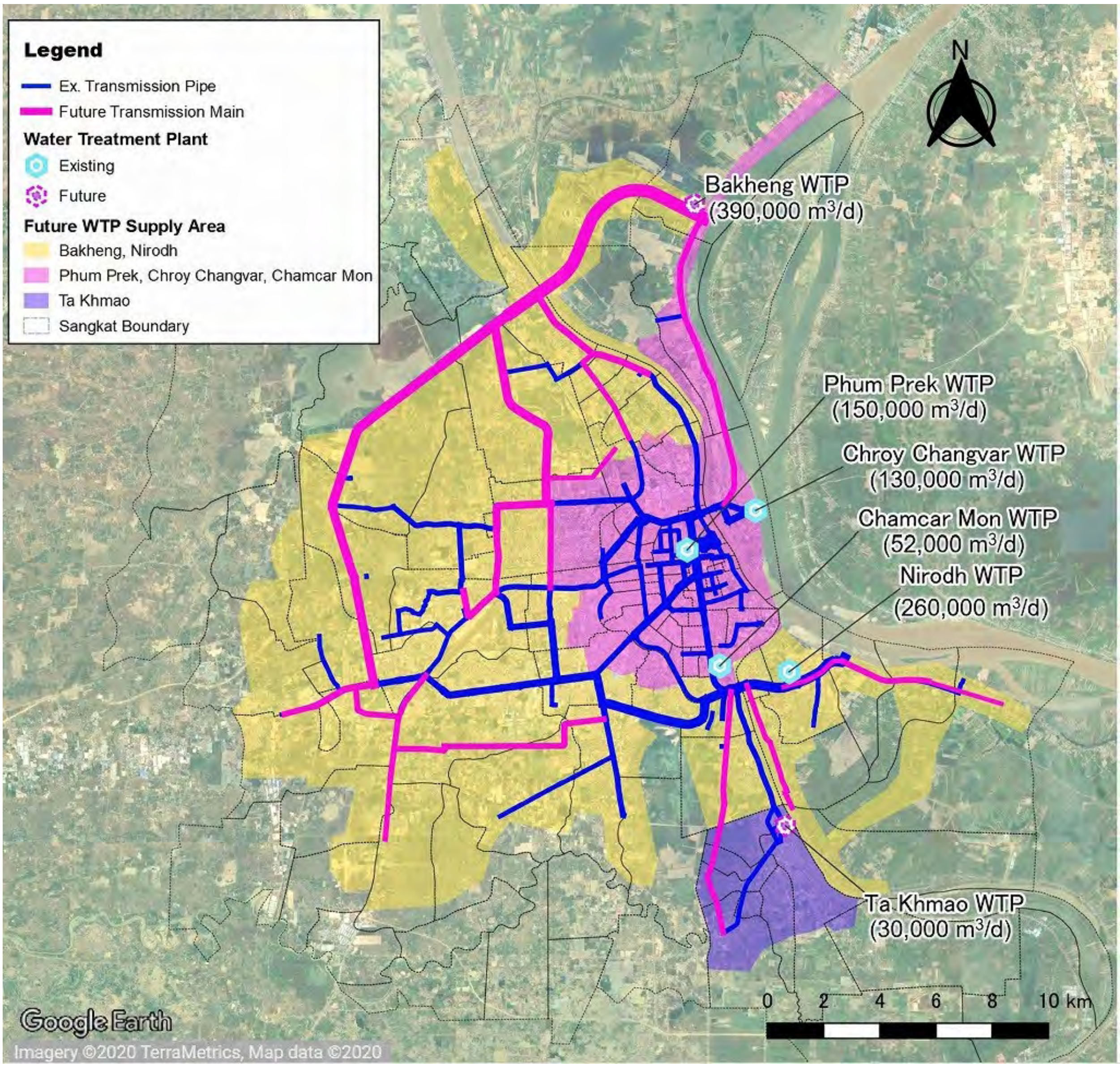


Figure 3.5-7 Outline of Distribution Area from WTP
Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)

As shown in ***Figure 3.5-7***, the distribution areas to be covered by Phum Prek, Chamkar Mon, and Chroy Changyar WTPs are determined by the production capacity of each WTP and the water demand of the surrounding areas. Nirodh WTP and Bakheng WTP will connect to the Outer Ring transmission mains and will supply the peri-urban areas of Phnom Penh.

3) Minimum Pressure

Calculated water pressure of the transmission system for day average water consumption in the year 2030 is shown in ***Figure 3.5-8***.

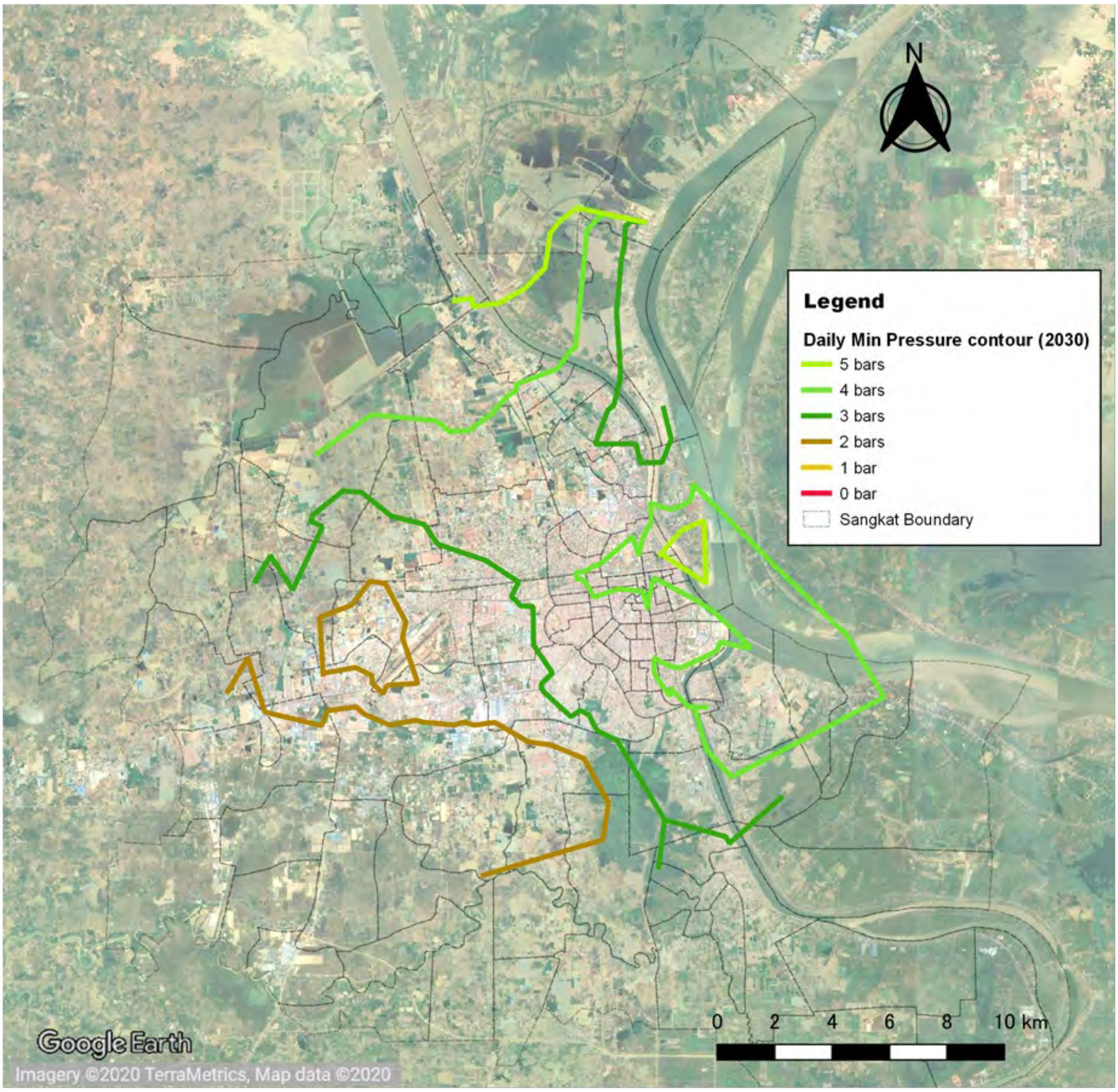
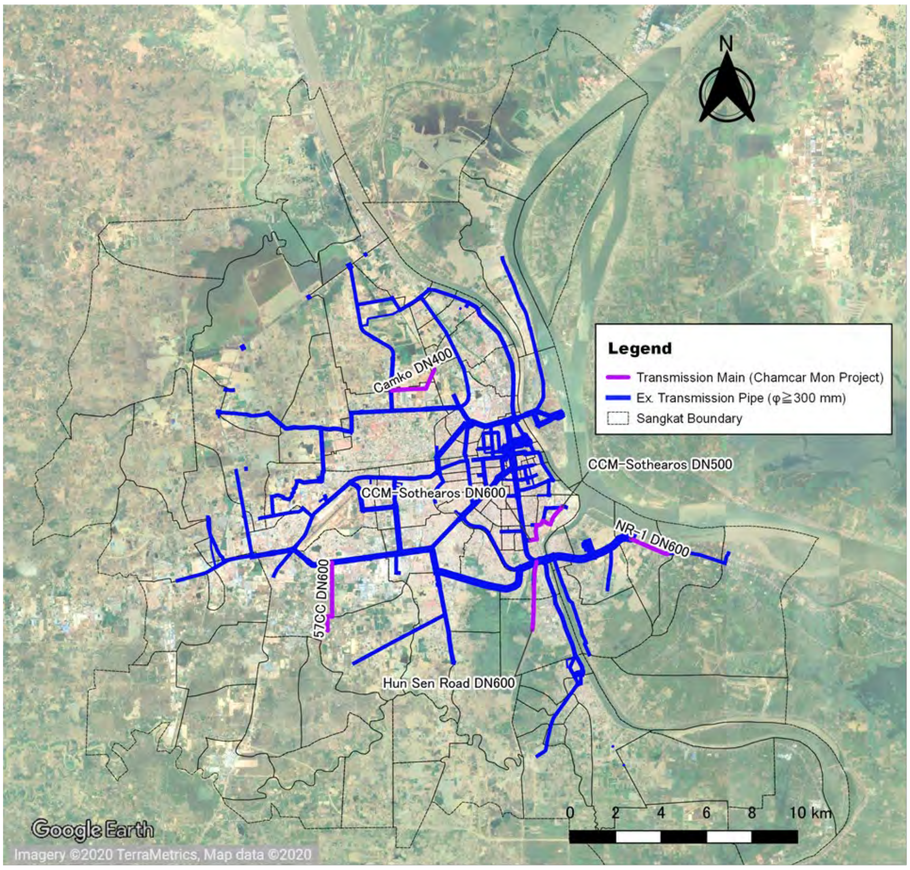


Figure 3.5-8 Minimum Pressure in 2030
Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)

According to the calculated water pressure in the transmission system, the water pressure of the south-west area of Phnom Penh (from the airport and along National Road 4) will be 2 bar. The low pressure is caused by the lack of sufficient transmission pipes. The water transmission plan needs to be re-evaluated before the completion of the Bakheng WTP to fix these issues.

(4) Comparison of the Third Master Plan (M/P 2017) and Current Situation

In order to ensure that facilities development will keep pace with the rapidly increasing water demand in Phnom Penh, re-evaluation of the water supply plans for each phase was planned in the Third Master Plan (M/P 2017). Therefore, water supply plans are currently being re-evaluated for the Chamcar Mon WTP Project (Phase 1) and Bakheng WTP Project (Phase 2). The water supply plan for the Chamcar Mon WTP Project is shown in ***Figure 3.5-9***.



Road	Dia-meter (mm)	Length (m)
CCM - Sothearos	500	1,000
Hun Sen Road (1/3)	600	3,000
57CC	600	3,230
NR1	600	1,745
Camko	400	2,450
Total of Transmission Mains of Chamcar Mon project		11,425

Figure 3.5-9 Transmission Mains Summary of Chamcar Mon Project
Source: JICA Data Collection Survey Team based on Third Master Plan (M/P 2017)

20.9 km of new main installation was planned in Phase 1 of the Third Master Plan (M/P 2017). However, it has not progressed beyond 11.4 km. During construction of the Chamcar Mon WTP, only three WTPs were in operation. This has led to continued water shortages in Phnom Penh. Transmission main installation must be resumed from Phase II and onwards.

In the Bakheng WTP Project (Phase II), the installations required in Phase I and diameters of the general network were re-evaluated.

Summary of the update of the transmission plan is shown in ***Figure 3.5-10***. Updated results of the Third Master Plan (M/P 2017) and the Bakheng WTP Project (Phase II) are shown in ***Table 3.5.5***.

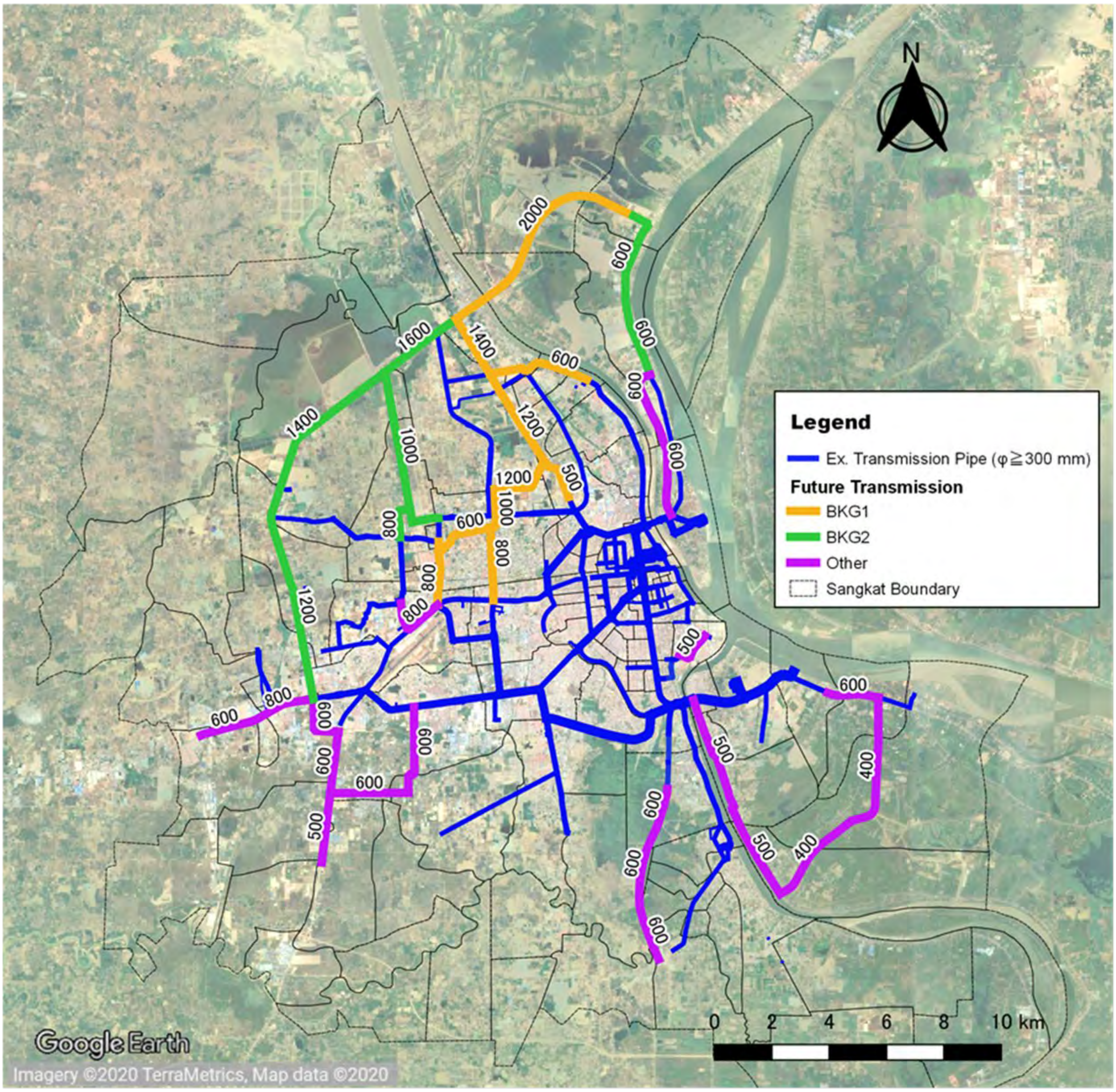


Figure 3.5-10 Outline of Reviewing Third Master Plan (M/P 2017)
Source: Bakheng Water Supply Project Inception Report

Table 3.5.5 Comparison Transmission Overall Program with Master Plan

Diameter (mm)	Third Master Plan Length (m)	Updated Plan (CCM+BKK) Length (m)	Difference Length (m) (Updated Plan - Third Master Plan)
400	5,800	10,900	5,100
500	10,300	16,210	5,910
600	44,200	42,385	-1,815
800	10,300	8,550	-1,750
1,000	2,600	6,410	3,810
1,200	13,800	12,380	-1,420
1,400	6,700	9,050	2,350
1,600	2,300	3,120	820
1,800	1,700	0	-1,700
2,000	7,900	8,800	900
Total	105,600	117,815	13,355

Source: Bakheng Water Supply Project Inception Report

After re-evaluation of the water transmission plan, it was revealed that the 106 km of transmission mains that were planned in the Third Master Plan (M/P 2017) will need to be extended by 12 km.

3.5.2 Water Distribution

(1) Design Principles

Expansion of distribution mains will be planned and managed by PPWSA based on urban conditions and needs of unserved areas and is not included in the Third Master Plan (M/P 2017). The Third Master Plan (M/P 2017) provides recommendations regarding the expansion program, improvement of the transmission network, and establishment of DMAs.

(2) Expansion Program

In 2016, 180 km of distribution mains were installed, and 20,000 households were newly connected. From the experiences of this implementation, the Third Master Plan (M/P 2017) recommends the installation of distribution mains as shown in ***Figure 3.5-11***.

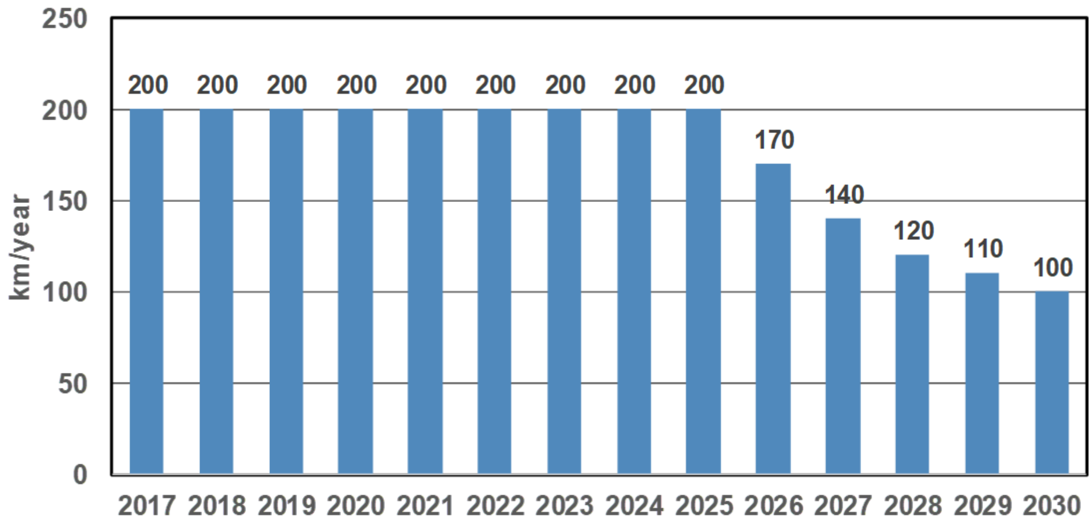


Figure 3.5-11 Annual Installation of Distribution Mains
Source: JICA Data Collection Survey Team based on Third Water Supply Master Plan (2016-2030)

(3) Improvement of Existing Network

As shown in ***Figure 3.5-12***, the water distribution network has a branch-shaped arrangement, and water in the network cannot circulate. This can cause low water pressure at the end of the distribution system. In the Third Master Plan (M/P 2017), water pressure will be improved by connecting the dead ends and creating a meshed network.

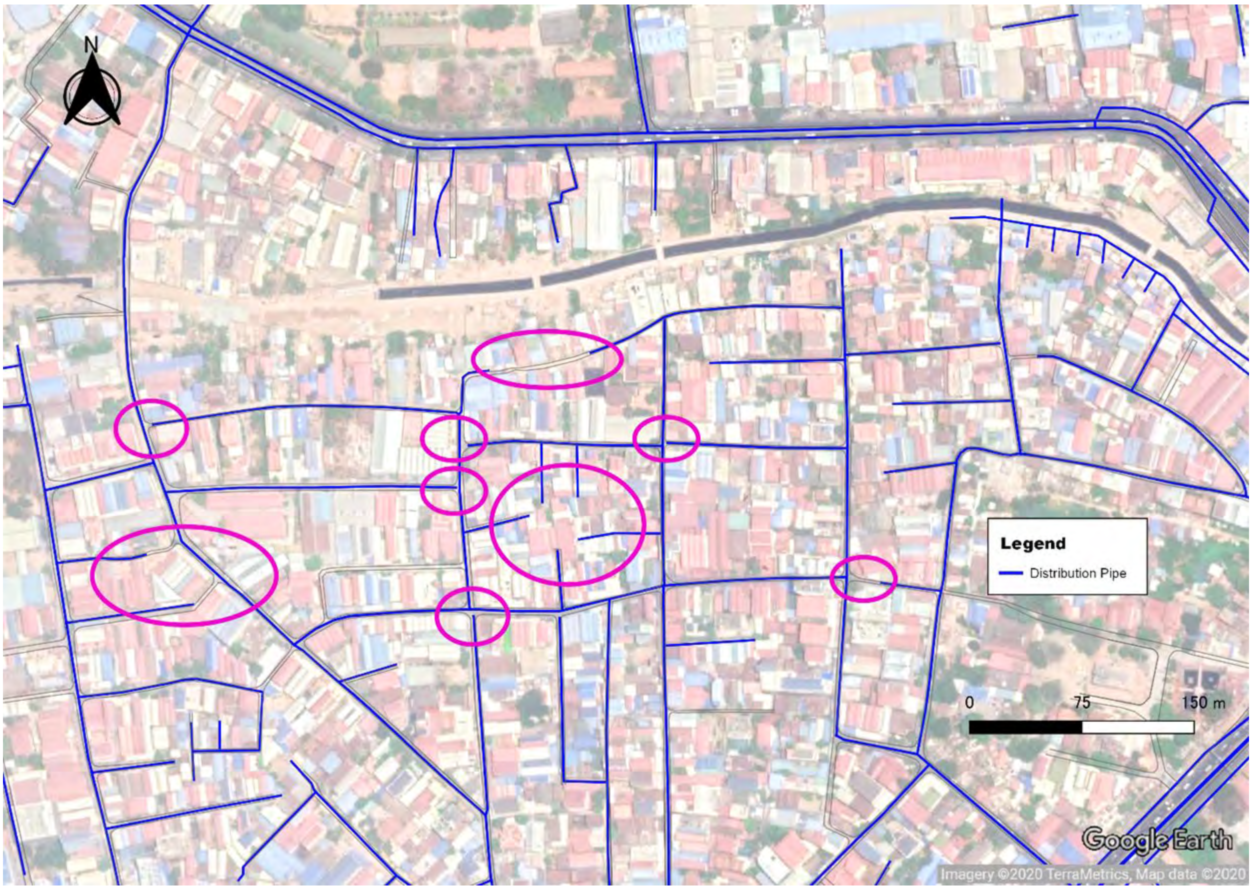


Figure 3.5-12 Improvement of Existing Network

Source: JICA Data Collection Survey Team based on Third Water Supply Master Plan (2016-2030)

(4) DMA

The Third Master Plan (M/P 2017) will utilize the existing DMAs and consider natural conditions during construction of new ones to complete the 173 DMAs planned for 2030. DMAs planned for 2030 are shown in ***Figure 3.5-13***.

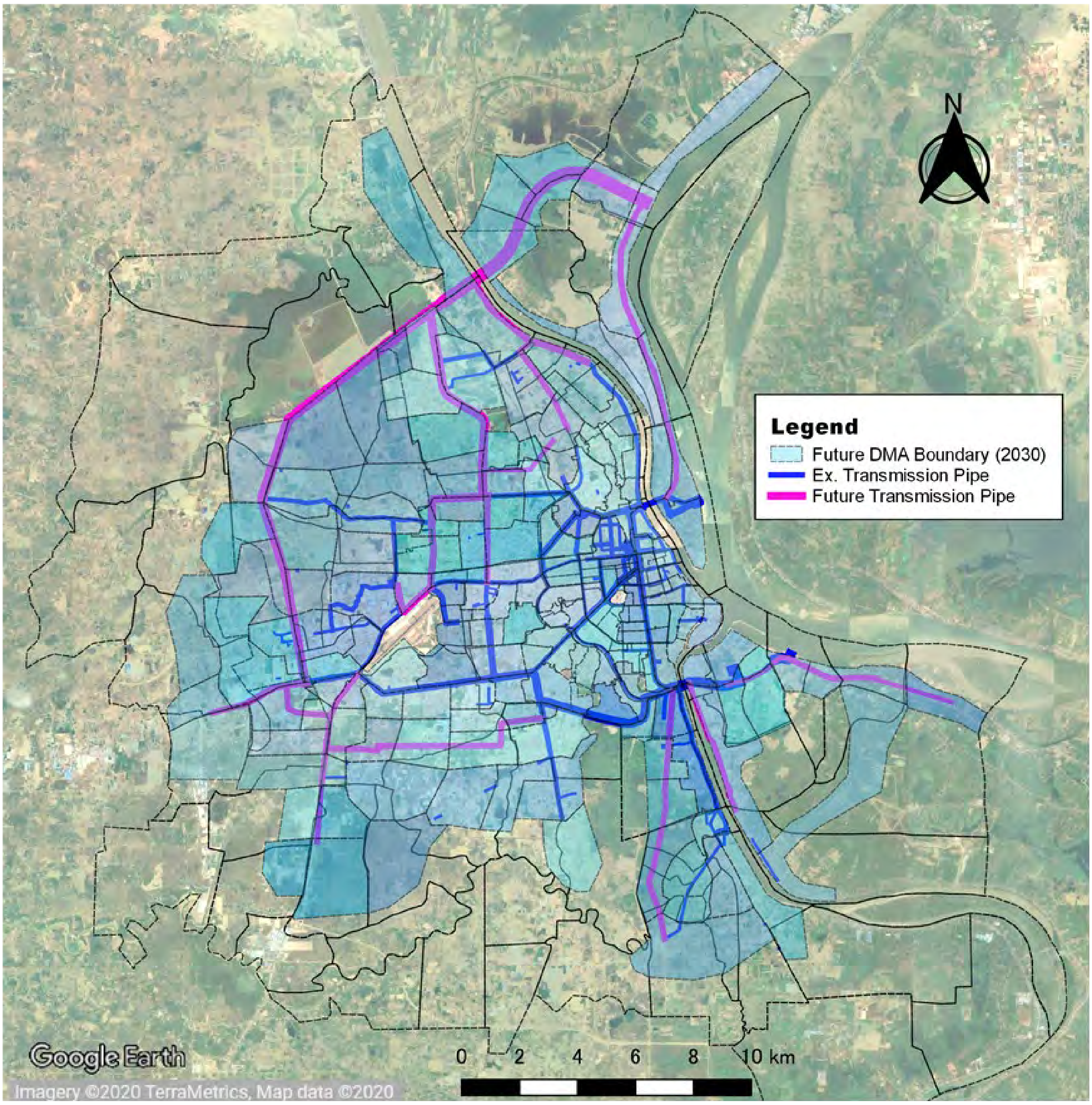


Figure 3.5-13 DMA in 2030

Source: JICA Data Collection Survey Team based on Third Water Supply Master Plan (2016-2030)

Planning and establishing new DMAs in the future will require careful consideration of urban conditions and requests for water service connections.

3.6 INSTITUTIONAL DEVELOPMENT

3.6.1 External Consideration

The Third Master Plan (M/P 2017) sorted out external factors that could have an impact on PPWSA. In the Survey, the factors that may affect the operation and financial status of PPWSA in the future are being examined based on the analysis of the Third Master Plan (M/P 2017) and organized as shown in the ***Table 3.6.1*** below. The items in *italics* were presented in the Third Master Plan (M/P 2017) and are still observed today.

Table 3.6.1 Comparison of Overall Program with the Third Master Plan

ISSUES	STAKES AND PROPOSITIONS CLARIFIED IN THE THIRD MASTER PLAN (M/P 2017)	POINTS TO BE CONFIRMED IN THE SURVEY
Legal framework and autonomy of PPWSA	(No description)	No major change was confirmed on legal framework on water supply services, and operation of water supply utilities recently. PPWSA seems to maintain its autonomy, looking free from the undue political interference. There is no change in the shareholders, the BOD's structure, or members. And water tariff has been revised twice as scheduled.
PPWSA's national role	How to use PPWSA's experience and expertise to improve water supply conditions throughout the country.	PPWSA has been providing on-site technical training courses to provincial waterworks as well as "knowledge sharing" to university students. New training center is under consideration for leveraging PPWSA's experiences to other waterworks. Management of some provincial waterworks were transferred to PPWSA. As Water and Sanitation Subsidy Branch, PPWSA have developed the support for implementation of projects in provincial waterworks. In addition to construction contracting, it has expanded to include survey, design, and tender document preparation as a consultant.
Sewerage and sanitation	Possibility that PPWSA will eventually be brought into the field of sewerage and wastewater treatment. Increased planning and cooperation with other stakeholders will be necessary.	The law on water supply and sanitation was not adopted. Water supply and sanitation are placed under separate ministries.
Privatization (through concession)	Possibility for PPWSA to engage in partial privatization / PSP (Private Sector Participation).	No PSP was implemented over the period. Currently, a survey is of the facility construction and its O&M contract project is underway.

Source: JICA Data Collection Survey Team

3.6.2 Institutional Development Plan

After analysing institutional capacity of PPWSA, the Third Master Plan (M/P 2017) assessed that PPWSA was "properly organized", and "already operating by international standards". The Third Master Plan (M/P 2017) suggested 10 key measures as a road map to maintain and improve the performance of PPWSA, which was expected to double its service in coming years. The 10 key measures are as follows:

Fields of key measures

1. Water tariffs
2. Human resources policy
3. Engineering and technical departments
4. Branch offices
5. Meter reading
6. Water quality monitoring & control
7. Maintenance
8. Equipment renewal management
9. Overall operation & energy efficiency

10. Vulnerability and emergency response

Those 10 key measures can be categorized into 1) organizational structure and management, 2) operation and maintenance management system, 3) finance and commercial management, and 4) human resource policy. This section will study the current situation of each measure according to the categories.

Table 3.6.2 summarizes the contents of the recommendations and the outline of the progress to date for the 10 measures listed above. An analysis of the current status and issues related to each are described in ***Chapter 9***, and human resource development is described in ***Chapter 10***.

Table 3.6.2 Measures, Objectives, and Activities in the Third Master Plan (M/P2017) and Progress in 2021

<table>
<tr><td colspan="4">1. Water tariffs</td></tr>
<tr><td>[Objective]</td><td colspan="3">Increase water tariffs in order to maintain a good level of profitability and generate enough cash to finance the investment program, while keeping water affordable for the poorest customers.</td></tr>
<tr><td>[Overall progress]</td><td colspan="3">Tariff has been revised two times in June 2017 and January 2020, which has had an effect in increasing the average water rates, especially in commercial connections. While this has contributed significantly to the increase in revenue, the average tariff has not risen to the level that was targeted.</td></tr>
<tr><td>[Validity of the measures]</td><td colspan="3">The need for tariff revision is very high and the recommendations are justified; PPWSA has also recognized the necessity and has been implementing measures.</td></tr>
<tr><td rowspan="10">[Progress of each activity]</td><td colspan="2">Activities to implement</td><td>Information provided by PPWSA</td></tr>
<tr><td colspan="2">for Phase 1 (2016-2018)</td><td></td></tr>
<tr><td colspan="2">change methodology of bills calculation to increase average tariff to around 1,500 KHR/m3 (as early as possible).</td><td>Methodology was not allowed to change.</td></tr>
<tr><td colspan="2">carry out a detailed customer survey and water tariff study.</td><td>Not implemented. Tariff study was based on the financial estimation of Chamkar Mon and Bak Kheng Projects.</td></tr>
<tr><td colspan="2">define desirable targets of water tariff at 2025 horizon.</td><td>Completed. It is considered to be reviewed at any period; 3 or 5 years. This Study also includes the review.</td></tr>
<tr><td colspan="2">prepare public opinion by communicating around and explaining the schedule and reasons for subsequent tariff increases.</td><td>Implemented. Published on TV, newspaper, Facebook, and other media prior to the implementation.</td></tr>
<tr><td colspan="2">for Phase 2 (2018-2022)</td><td></td></tr>
<tr><td colspan="2">increase tariffs to reach the target defined.</td><td>Revised in 2017 and 2020. Although the target was set at 1500 R/m3 at average, the actual average is 1,250 R/m3 domestic and 1,350 R/m3 for non-domestic consumption, The gap is caused by the amount of consumption due to the Pandemic.</td></tr>
<tr><td colspan="2">use simulation model to anticipate needs for additional tariff increases.</td><td>Not implemented. Using MS Excel.</td></tr>
<tr><td colspan="4">2. Human Resources policy</td></tr>
<tr><td>[Objective]</td><td colspan="3">Define a comprehensive Human Resources policy based on the following five pillars: DETECT, RECRUIT, TRAIN, MOTIVATE, REPLACE</td></tr>
<tr><td>[Overall progress]</td><td colspan="3">Measures to prevent the turnover of young technical staff have been improved. Issues in developing future executive candidates and core staff, and in passing on technology and knowledge to the next generation.</td></tr>
<tr><td>[Validity of the measures]</td><td colspan="3">The need to strengthen the human resources policy is highly significant and it is beneficial to PPWSA that various measures have been presented. Some of the measures are not really fit to the actual situation of PPWSA and therefore considered unnecessary to be implemented.</td></tr>
<tr><td rowspan="4">[Progress of each activity]</td><td colspan="2">Activities to implement</td><td>Information provided by PPWSA</td></tr>
<tr><td colspan="2">for Phase 1 (2016-2018)</td><td></td></tr>
<tr><td rowspan="2">DETECT</td><td>Set up a strategic partnership with training institutions (ITC…) to detect high-potential students.</td><td>Not implemented.</td></tr>
<tr><td>Align detection of potentials with needs expressed by</td><td>Continuously implemented. The</td></tr>
</table>

		department managers (set up annual recruitment plan with skills requirements).	recruitment number is defined as annual plan.
		Reinforce the offer of internship positions, with clear operational duties under a defined supervisor (not just observation) to identify students worth hiring.	Implemented
	RECRUIT	Make PPWSA more attractive for young graduates (better initial salary).	Implemented
		Prepare and implement proper jobs description to attract young graduates.	It is difficult to show job descriptions to applicants in advance, as multiple staff members are hired and then assigned tasks.
		Facilitate integration of new recruits by defining a standard integration path (e.g. orientation circuit including HR / IT / visit of all Depts, appointment of a mentor, quarterly new-comers seminar…).	Continuous implemented
	TRAIN	Define ambitions targets of training in terms of man-days (in-house, in Cambodia and abroad) and expenditures for each staff category.	implemented.
		Increase massively the budget dedicated to training (x10).	Many courses are conducted internally, which costs less. Unnecessary to improve now.
		Train department managers to the concept of Training Needs Assessment.	Not implemented
		Prepare a standardized catalogue of in-house training.	Completed
		Identify and prepare strategic partnership with outside training institutions, particularly abroad (e.g. IWA).	Continuing
	MOTIVATE	Strengthen the incentives system (bonus / penalty).	Implemented
		Increase initial salary of high-level staff (see "recruit").	Already applied for new engineering graduates.
		Plan significant increase of salaries for experienced high-level staff to offer better perspectives.	Unnecessary because high-level staff are well motivated, and turnover is not an issue.
	REPLACE	Formalize backup plan for executive staff due to retire in the next 10-15 years	Not formally established.
	for Phase 2 (2018-2022)		
	DETECT	Strengthen cooperation with training institutions by setting up special courses / programs related to water management, and dispatching PPWSA staff to teach classes (for example ITC is currently trying to set up a "water" program in partnership with foreign universities).	Not implemented
	RECRUIT	Implement a "graduate" program for technical graduates whereby they get to spend 1 to 2 years in various positions (works, water production, maintenance, engineering…) before being assigned to a long-term position.	not implemented
	TRAIN	Implement a systematic yearly Training Needs Assessment in each Department (short and long-term)	Continuously implemented
		Prepare a complete learning path with logical series of trainings for each staff category.	Not implemented
		Develop e-learning sessions.	Not implemented
		Develop training through certifying courses (Master's Degree, MBA).	Ongoing
		Systematize post-training assessment and adjust training policy accordingly.	Ongoing
	MOTIVATE	Increase salaries of high-level staff.	Completed
		Develop staff's annual performance assessment.	Completed
		Record staff's rise in skills and link their evolution (grades, positions and salaries) to training achievements and performance assessment.	Completed
	REPLACE	Intensify training for identified future executive staff,	Ongoing

		particularly certifying courses	
		Increase delegation of duties and organize progressive transfer of responsibilities.	Not implemented
	Phase 3 (2022-2030)		
	TRAIN	Set up exchange programs with other water utilities to allow staff spend several weeks / months observing practices in other locations.	Not implemented
		Leverage the experience of senior, retiring staff by hiring them as special training consultants to ensure transfer of knowledge.	Preparing
	MOTIVATE	Align salaries of high-level staff on the private sector	Completed
	REPLACE	Replace retiring staff	Completed
3. Create Engineering and restructure of Technical Department			
[Objective]	Deepen the collaboration between the two departments related to technology, Planning and Project Department and Production and Distribution Department, and clarify the supervising office and responsibilities for engineering that extends across the two departments.		
[Overall progress]	Water Supply Management Office was established under Planning and Project Department		
[Validity of the measures]	There is a substantial need to strengthen the proposed areas. As facilities and operations continue to expand and become more complex, the optimal organizational structure needs to be considered on a continuous basis.		
[Progress of each activity]	**Activities to implement**		**Information provided by PPWSA**
	for Phase 1 (2016-2018)		
	Decide of the future organization and take appropriate measures to prepare the change (particularly future SOP, procedures and staff appointment).		Implemented. Basically, based on the duties proposed in M/P 2017 were sorted to move.
	Prepare temporary SOP related to the use and maintenance of the telemetry system (water losses monitoring) for operation until the new organization.		Implemented.
	Create an independent GIS office and strengthen implementation of SOP.		Implemented.
	Identify the needs in terms of HR for the new Engineering division and start recruitment.		Continuously implemented for further staff's assignment.
	for Phase 2 (2018-2022)		
	Fully implement the new organization along with procedures		Implemented
	Implement systematic use of hydraulic modelling for project verification prior to validation.		Under procurement of "Water Gym" equipping many functions such as design hydraulic modeling based on demand, monitoring, and training of those functions.
	Implement use of hydraulic modelling for network performance assessment and improvement of existing network.		Ditto
	Appoint a team / staff in charge of "technology intelligence" and innovation through monitoring of the tools and techniques available on the market and applied in other water utilities, and adaptation of these in PPWSA.		Under consideration. Need to be discussed in this study.
4. Decentralize duties and staff to branch offices			
[Objective]	Decentralize PPWSA and transfer duties to branch offices in order to improve customer service and gain efficiency.		
[Overall progress]	Commercial: Operations of meter reading, billing collection, and customer service have been transferred to 6 branches including Chbar Ampov. After the completion of Bakheng project, additional two branch offices in the western areas will be considered. Technical: Water loss control, leak detection and repair teams have been transferred to 4 branch offices.		
[Validity of the measures]	As the expansion of service areas accelerates, the proposals are reasonable and important in terms of improving customer service as well.		
[Progress of each activity]	**Activities to implement**		**Information provided by PPWSA**
	for Phase 1 (2016-2018)		
	Study the opportunity to decentralize additional services and prepare the roadmap for decentralization		Completed.

	Prepare facilities and infrastructure and define procedures	Implemented.
	Identify and train branch office managers	Implemented based on SOPs.
	Prepare staff reorganization based on proximity between home and future branch offices	Implemented.
	Set up facilities for workers teams (O&M, construction) and start using them as local base	Implemented.
	for Phase 2 (2018-2022)	
	Implement the decentralization plan step by step by transfer of teams and responsibilities:	
	1. Bill collectors and revenue offices	Implemented.
	2. Full customer services	Implemented.
	3. House connection teams	Not implemented because of the limited number of skillful staff and the control of stocks.
	4. Network maintenance and leaks detection teams	Implemented.
5. Meter reading		
[Objective]	Increase meter reading reliability, particularly for large (strategic) customers.	
[Overall progress]	Handy terminals have been equipped to all meter readers by in May 2017. Data handling errors have been reduced and the meter reading cycle has been shortened. This has also led to a reduction in the number of meter readers and an increase in on-time payments. Installed electromagnetic flowmeter for large consumption customers and completed the switch them to monthly billing. Automatic meter reading is being tested.	
[Validity of the measures]	The recommendations are expected to have an immediate and significant impact in terms of the reduction of labor cost and data handling errors, and are given high priority by PPWSA.	
[Progress of each activity]	**Activities to implement**	**Information provided by PPWSA**
	for Phase 1 (2016-2018)	
	Equip meter readers with hand computers	Completed in May 2017.
	Define, procure and implement data validation software tool	Implemented and defined in SOP.
	Switch to monthly reading for strategic customers	Completed.
	for Phase 2 (2018-2022)	
	Implement Automatic Meter Reading for strategic customers	Under trail for few customers.
	Switch to monthly billing for all strategic customers	Completed.
6. Strengthening of water quality monitoring		
[Objective]	Review the water quality monitoring protocol and control, and leverage the results obtained to improve water quality and anticipate evolution of raw water quality.	
[Overall progress]	No change in monitoring parameters and frequency; ISO 17025 certification for 5 items in 2020. Calibration and preventive maintenance of analytical instruments and annual sample analysis outside Cambodia started.	
[Validity of the measures]	The need for capacity building is critical, and medium- to long-term commitment is necessary. Although various measures have been presented, it is difficult to see the way forward for measures that require cross-organizational or upper management initiatives.	
[Progress of each activity]	**Activities to implement**	**Information provided by PPWSA**
	for Phase 1 (2016-2018)	
	Set up stringent water quality standards	Not implemented. Unnecessary because PPWSA's standard is based on the national and WHO's standard.
	Review all analyses protocols and make sure that they are correct and relevant with PPWSA objectives (preparation for the ISO 17025 certification could help in this process).	Implemented. Laboratory in Niroth WTP was certified for 5 parameters with ISO 17025 in De. 2020. Formulated manuals and SOPs for data management and quality control.
	Start monitoring parameters currently not measured.	Not implemented (but willing to do). A sample of treated water at WTP has been analyzed in Singapore for 160 items annually since 2018.
	Define emergency procedures to be followed in case of raw water contamination and train staff to their implementation.	Not implemented. Response to abnormalities has been considered, but not documented.
	Prepare procedures and appoint staff to ensure proper maintenance and calibration of all equipment.	The analytical instrument has been sent to Hong Kong and Vietnam for calibration sequentially, which is scheduled to be completed in 2022. In addition, a new maintenance team for laboratory equipment has been established jointly with the Mechanical and Electrical

		Office, and maintenance items and schedules have been defined.
	Include into the GIS the results of water quality analyses performed on the network to allow better understanding of water quality.	Monitoring of residual chlorine is planned in the future using SCADA used to manage the volume of treated water and distributed water.
	for Phase 2 (2018-2022)	
	Reinforce laboratory staff with a water quality expert able to provide critical analysis and anticipation of quality evolution.	Not Implemented. Need to increase staff number. Too busy in regular operations. Necessary to have support from higher level/outside to increase those capacity.
	Prepare and implement stringent procedures to be implemented in case of noncompliance of treated water quality with the standards (at WTP level or in the network).	Not implemented. Even if water quality worsens, it is difficult to take measures that will lead to a decrease of supplying water volume, such as shutting down the treatment system, due to the current water shortage.
	Implement continuous monitoring on chlorine concentration on critical points of the water network.	Under consideration. In the future, water quality will be tested periodically at the points where the water quality in the distribution network deteriorates (more than 10 locations). Currently, flow rate and water pressure are measured at the DMA inlet, but looking into including residual chlorine, turbidity, pH, and conductivity.
	Develop capacity to perform advanced biological analyses.	The algae problem currently occurs only during rainy season at Phum Prek. Need to improve capacity but need external support.
	Implement a full Laboratory Information Management System software (LIMS) and connect all WTP laboratories to this central software	Under planning. It is planned that SCADA will be used to monitor the water quality at all WTPs and distribution network.
	for Phase 3 (2022-2030)	
	Perform regular river sediment analyses.	Responsibilities of MOWRAM. Although it is considered necessary in the future, it is desirable to be able to mutually exchange data.
	Apply for ISO 22000 certification related to potable water quality.	Not implemented. PPWSA has WSP already.
	Apply for ISO 17025 certification related to laboratory management.	Dec. 2020: 5 items certified in Nirotdh lab. Plans to increase the number of analytes and certify other labs in the future.
7. Systematize maintenance		
[Objective]	Improve procedures and tools and create a Maintenance Audit Office to make sure that maintenance is properly performed	
[Overall progress]	There is no change in the organization; the Inspection Office monitors the level of compliance with SOPs at each workplace. There is little change in the maintenance and management system.	
[Validity of the measures]	Although this is the important proposal which highlights the importance of maintenance in PPWSA, where the facility development is emphasized, its significance has been not fully shared within the PPWSA.	
[Progress of each activity]	**Activities to implement**	**Information provided by PPWSA**
	for Phase 1 (2016-2018)	
	Create a Maintenance Audit Office within the Production & Distribution Office / Division. The office will be in charge of conducting quarterly audit of equipment condition and respect of maintenance schedule in each WTP and on the network.	No change. Inspection Office conducts general inspection of all offices to confirm if an office follows SOP. or not.
	Implement more stringent procedures for WTP cleaning.	No change.
	Implement regular (bi-annual) TWT cleaning and send deposits to the laboratory for analysis.	Not implemented. (The meaning of sediment analysis is not necessary at present, as it is covered by the analysis items of the current water quality monitoring.)
	Train and assign staff for the maintenance of automation and measurement equipment.	Not implemented.
	Implement a strict policy with zero tolerance for defective equipment (corrective maintenance).	Not implemented.
	Revise maintenance schedule of all equipment according to	Not implemented.

	manufacturer's recommendations (preventive maintenance).	
	Prepare maintenance logbooks to trace all maintenance actions.	Not implemented.
	Define program of valves operation and pipes flushing. Assign staff for program implementation (preventive maintenance).	Implementing for D260mm to D60mm pipes. (willing to do transmission pipe and raw water conveyance pipe as well)
	for Phase 2 (2018-2022)	
	Carry out criticality analysis of equipment. Revise maintenance schedules according to findings.	Implemented according to SOP. SOPs have been reviewed annually.
	Train electrical department staff to measure pumps efficiency. Implement regular measurement (at least every two years for each pump).	Not implemented. (but willing to do)
	Implement a Computerized Maintenance Management Software (CMMS) to trace equipment maintenance and issue reminders on necessary actions.	Not implemented, (but willing to integrate those function in SCADA system TOPCAPI).
	Use the CMMS to provide KPI on critical equipment performance and availability for the use of the Maintenance Audit Office.	Not implemented.
	Apply for ISO 55001 certification related to asset management systems	Not implemented.
8. Equipment renewal management		
[Objective]	Implement systematic data collection about pipes in order to have enough data when preventive pipes replacement becomes necessary.	
[Overall progress]	The asset management system consolidates information on leak points, meters and pipes, and relocations. At the time of leak repair, observation and recording of the corrosion and other conditions of buried pipes is started along with the repair records.	
[Validity of the measures]	Data collection about pipes is of high importance not only for those renewal but also for water loss management, which is recognized by PPWSA. However, the recommendations for systematic analysis of pipe material are evaluated as not highly necessary and feasible.	
[Progress of each activity]	**Activities to implement**	**Information provided by PPWSA**
	for Phase 1 (2016-2018)	
	Implement systematic assessment of pipes internal condition each time a pipe has to be cut	Implemented. A software for asset management "KIS" started its operation in 2016, which includes records of leakage repairing, information of meters and valves, and relocation of pipes. At leakage repairing, the status of the pipe is also recorded with pictures; pipe size, internal/external corrosion conditions.
	Implement systematic non-destructive analysis of pipe wall thickness each time a pipe is excavated	Not implemented.
	for Phase 2 (2018-2022)	
	Set up laboratory facilities for HDPE samples analysis.	Not implemented. (unnecessary)
	Implement systematic sampling of HDPE pipes for laboratory analysis during leaks repair.	Not implemented.
	Implement systematic corrosion analysis on ductile iron pipes during works.	Not implemented.
9. Overall operation & energy efficiency		
[Objective]	Create a centralized dispatching unit in charge of real-time management of water production and distribution, and optimize pumping to achieve energy savings.	
[Overall progress]	Each WTP is operated by SCADA, and the status can be viewed online. However, since transmission and distribution network from each WTP are not separated, it is difficult to control water supplying to each area by only controlling the amount of water transmitted from WTPs. Integration of all SCADA is being considered by the Bakheng project.	
[Validity of the measures]	It will be more important in the future when multiple WTPs are in operation than when the M/P was formulated; since the M/P presented the recommendations in advance, it helps to undertake them in a timely manner.	
[Progress of each activity]	**Activities to implement**	**Information provided by PPWSA**
	for Phase 1 (2016-2018)	
	Create additional real-time measurement points (flow rate and pressure)	Not implemented. Flow rate and

	on the transmission network using electromagnetic insertion probes. Connect these points to the current RTU system.	pressure are continuously monitored at EL tanks and outlet of WTPs. At the inlet of all DMAs, flow rate and pressure are monitored and recorded every minute and the data is transmitted to head office daily.
	Include the requirements for a future control and dispatching room into the design of the new buildings planned at PPWSA main office, and prepare IT infrastructure accordingly.	Unnecessary.
	Recruit / identify and start training staff to the job of dispatcher (mostly external training).	Implemented. Some young staff have been provided specified training occasions.
	for Phase 2 (2018-2022)	
	Create the dispatching unit after completion of Bakheng WPF Stage 1.	Not implemented. (planned to implement)
	Perform feasibility study of implementation of an optimization tool for management of water pumping.	Not implemented but would be conducted during MP study.
	for Phase 3 (2022-2030)	
	Implement the real-time optimization tool for management of water pumping, if it can provide energy savings.	Not implemented. After BKN Project completion.
10. Vulnerability and emergency response		
[Objective]	Assess general vulnerability of PPWSA to internal or external issues, define crisis scenarios and implement crisis management procedures.	
[Overall progress]	The responsible section has not been specified, and the activities are not implemented.	
[Validity of the measures]	As a city grows, the expectation for continuity of water services increases, thus it is crucial to strengthen emergency response in steps, a need that has been re-emphasized under the COVID-19 pandemic.	
[Progress of each activity]	**Activities to implement**	**Information provided by PPWSA**
	for Phase 1 (2016-2018)	Although emergency responses have been defined in SOPs for some operations such as chlorine accidents and large leaks, emergency responses for the entire organization have not been implemented due to the lack of a specified office in charge.
	Carry out vulnerability studies, define crisis scenarios and prepare procedures for crisis management.	
	for Phase 2 (2018-2022)	
	Implement procedures for crisis management.	
	Perform regular training & crisis simulation exercises.	
	for Phase 3 (2022-2030)	
	Implement full-scale facilities for crisis management (situation room).	
	Implement 24/7 emergency on-call service.	

Source: JICA Study Team

CHAPTER 4 WATER DEMAND PROJECTION

4.1 POPULATION DATA AND BILLING DATA

4.1.1 Population Data

(1) Population Data

Table 4.1.1 shows the list of population data that was available.

Table 4.1.1 List of Population Data

Item	Publisher	Year	Description
Census	National Institute of Statistics (NIS)	2008, 2019	• Available at the Sangkat level only in 2019
Commune data base (CDB)	National Institute of Statistics (NIS)	2010-2017	• Available at the Sangkat level • CDB includes only permanent residence
Population projection	DoP* Phnom Penh	2020	• Population projection based on the Census 2019
	United Nations	2019	• World Urbanization Prospects - United Nations population estimates and projections of major Urban Agglomerations
		2014	• Same as above • Utilized in "World Bank, Urban development in Phnom Penh (Dec. 2017)"
	JICA	2014	• Studied in "The Project for Comprehensive Urban Transport Plan in Phnom Penh Capital City"

* Commune Database: CDB, Department of Planning: DoP, National Institute of Statistics: NIS
Source: JICA Data Collection Survey Team

Comments on the population data are as follows:

- Population data at the Sangkat level is available only in the Census (2019) and Commune Database (hereinafter referred to as "CDB").
- CDB does not include temporary residents such as workers and students from outside of Phnom Penh. So, CDB does not represent the real situation of population in Phnom Penh.
- According to discussions with PPWSA, Census data also does not show the actual population. Some of the population was not surveyed by the Census.

Considering these facts about the population data, it is thought that there is no accurate accounting of the actual population in Phnom Penh.

(2) Comparison of Population Data

Population data and forecasts drawn from the above sources are compared in ***Figure 4.1.1***. As shown in the figure, population forecasts which were made recently, such as United Nations (hereinafter referred to as "UN") 2020 and Projection (DoP of Phnom Penh) forecast further population increases in the future.

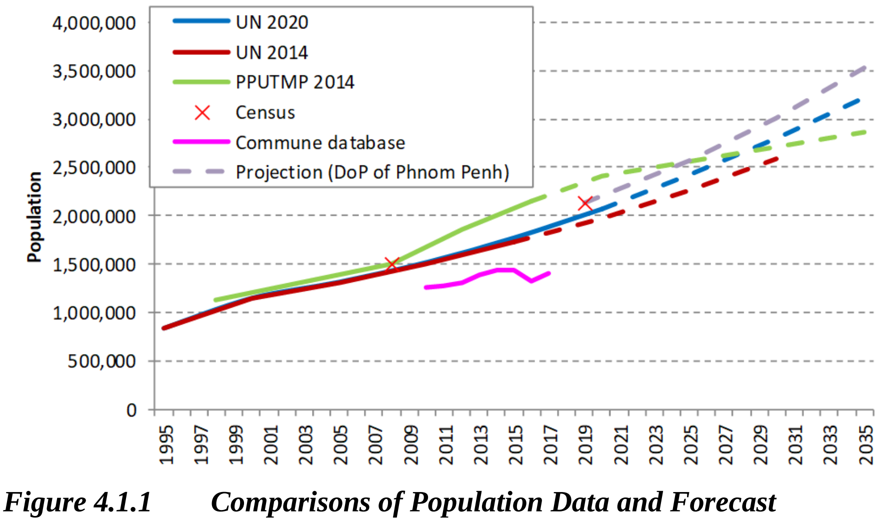


Figure 4.1.1 Comparisons of Population Data and Forecast
Source: Prepared by JICA Data Collection Survey Team based on the information listed in ***Table 4.1.1***

(3) Situation of Urbanization

The "Urban Development in Phnom Penh" report prepared by the World Bank in 2017 estimates that the level of urbanization in Cambodia is 21%, as shown in ***Table 4.1.2***. The report also points out that urbanization of 21% is far below what would be predicted based on the country's per capita GDP. Urbanization levels of similar countries are shown in ***Table 4.1.2***.

Therefore, further urbanization in Cambodia is expected in the near future. It can be thought that the further urbanization of Cambodia will lead to further urbanization of Phnom Penh.

Table 4.1.2 Situation of Urbanization in South-Eastern Asia

MAJOR AREA, REGION, AND COUNTRY	POPULATION (THOUSANDS)			PERCENTAGE URBAN
	Population in Urban Areas	Population in Rural Areas	Total	
South-Eastern Asia	294,409	331,573	625,982	47
Brunei Darussalam	325	98	423	77
Cambodia	3,161	12,247	15,408	21
Indonesia	133,999	118,813	252,812	53
Lao People's Democratic Republic	2,589	4,305	6,894	38
Malaysia	22,342	7,846	30,188	74
Myanmar	18,023	35,696	53,719	34
Philippines	44,531	55,566	100,096	44
Singapore	5,517	-	5,517	100
Thailand	33,056	34,167	67,223	49
Timor-Leste	370	782	1,152	32
Viet Nam	30,495	62,053	92,548	33

Source: United Nations, World Urbanization Prospects, 2014 Revision

Source: World Development Indicators 2014 (World Bank, Urban development in Phnom Penh, Dec. 2017)

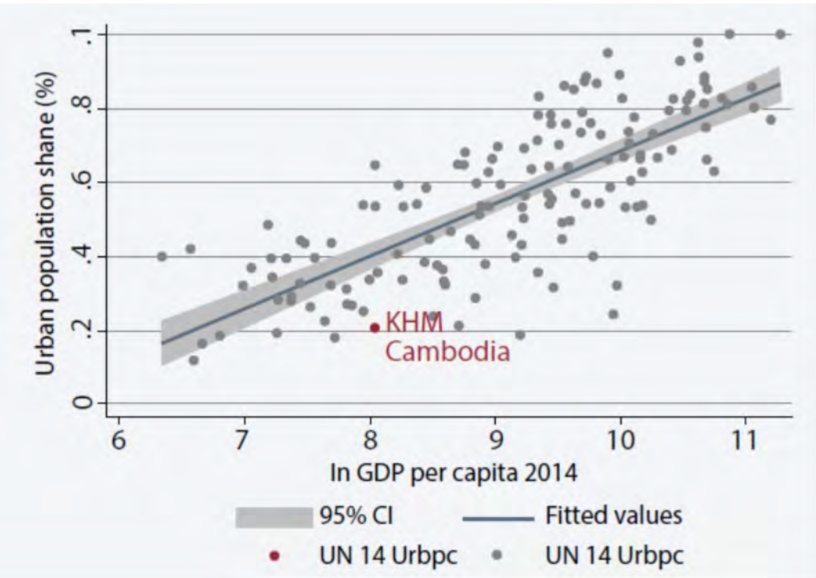


Figure 4.1.2 Urban population share (%) vs GDP per Capita, Global Benchmarks 2014

Source: World Development Indicators 2014 (World Bank, Urban development in Phnom Penh, Dec. 2017)

(4) Summary of Population Data and Population in Phnom Penh

Summary of the population data and population in Phnom Penh are as follows:

- It is though that the existing data do not show the actual population in Phnom Penh.
- Further population increase in Phnom Penh is expected as Cambodia continues to urbanize.

It is difficult to carry out population projection for water demand forecasts considering the lack of reliable population data. However, it is almost certain that the population of Phnom Penh will continue to increase.

4.1.2 Billing Data

The summary of the billed amount at the Khan level is shown in ***Table 4.1.3*** and ***Figure 4.1.3***. The following situations are observed from the billing data.

- The billed amount drastically decreased in 2020. The main reason is assumed as follows:
  - ➢ It is probable that the impact of the COVID-19 pandemic reduced the number of foreign travellers and this led workers who had migrated to Phnom Penh capital to work return to their hometowns.
- The billed amount in 2017 was higher than 2018. The main reason is assumed as follows:
  - ➢ Operation of Chamcar Mon WTP was stopped in August 2017 for re-construction and re-started operation in November 2019.
- Aside from these two cases, a constant rising trend can be observed in each Khan.

Table 4.1.3 Billed Amount from 2010 to 2020

unit: m^3/day

Khan	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
01 Daun Penh	31,442	30,591	31,572	32,675	33,096	33,319	34,064	36,667	33,430	35,188	28,372
02 Prampir Makara	18,178	17,890	18,122	18,750	18,579	18,578	19,151	20,819	19,003	19,611	15,926
03 Chamkar Mon	43,443	43,571	45,677	47,543	50,397	52,374	54,482	63,142	56,575	59,855	49,425
04 Tuol Kouk	35,392	35,674	36,529	38,597	39,679	40,997	41,743	45,769	41,696	42,280	35,942
05 Ruessey Keo	20,117	22,529	25,727	29,383	33,588	38,015	41,045	46,546	47,111	49,088	47,113
06 Mean Chey	33,060	36,053	40,490	44,985	49,350	54,054	57,587	63,704	57,915	61,151	53,820
07 Dangkao	2,154	3,114	4,950	7,267	9,494	11,730	15,818	23,698	24,291	27,935	30,504
08 Pou Senchey	33,422	38,426	46,543	54,748	59,238	69,900	76,664	90,955	92,605	99,714	92,807
09 Saensokh	22,492	25,532	30,652	36,498	41,559	48,624	53,973	65,199	64,659	70,200	65,007
10 Chrouy Changvar	5,210	5,574	6,116	6,913	7,957	9,552	9,943	11,366	13,226	14,232	15,344
11 Chbar Ampov	6,150	7,174	9,273	12,046	13,781	16,603	18,863	20,920	27,559	33,178	31,648
12 Preaek Pnov	66	229	487	767	934	1,232	1,664	2,369	3,348	4,555	4,997
13 Ta Khmao	6,620	6,925	7,493	8,558	10,226	11,443	13,588	15,678	15,377	16,282	15,582
Total	257,746	273,282	303,631	338,730	367,878	406,421	438,585	506,832	496,795	533,269	486,487

Note: 03 Chamkar Mon" includes from 2019 both new Chamkar Mon District and Boeng Kengkang District.
Source: Billing data provided by PPWSA

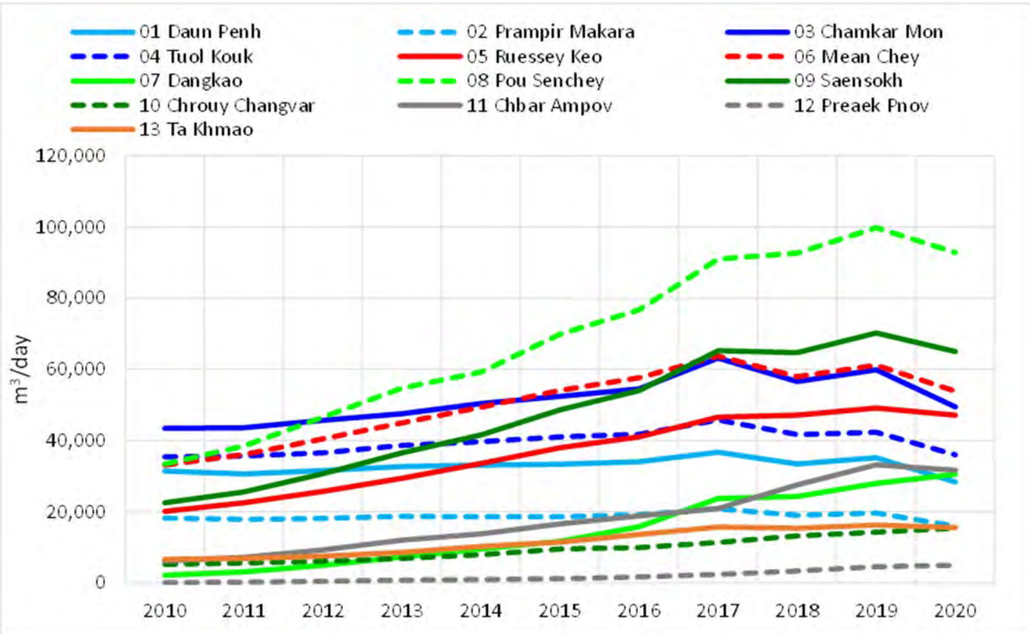


Figure 4.1.3 Billed Amount Based on the Billing Data
Source: Billing data provided by PPWSA

It is sometimes thought that billing data can be used directly for water demand forecasting, since the billing data shows the actual amount of water used and billing trends tend to be similar to population trends. However, it should be noted that billed amount does not necessarily represent water demand, especially since the production capacity of WTPs in Phnom Penh has been insufficient in recent years.

4.2 WATER DEMAND FORECAST METHODOLOGY

4.2.1 Methodology of Water Demand Forecast

(1) Data to Be Used for Water Demand Forecast

When the methodology of water demand forecast for Phnom Penh is studied, the followings must be considered:

- The available population data does not show the actual population in Phnom Penh.
- The population of Phnom Penh is expected to increase further.
- The billing data show the actual amount of water use by customers. However, the billed amount does not show the actual water demand due to insufficient WTP capacity.
- The water use in each Khan was confirmed to have constant increasing trends by the analysis of the billing data as shown in "**4.1.2 Billing Data**". Therefore, it is appropriate to forecast future water usage patterns by use of the billing data.

Based on the above, the following conclusions are reached for the implementation of water demand forecast:

- It is not practical to carry out population projection for water demand forecast since the reliability of population data is low. Therefore, population projection is not carried out.
- It is practical to carry out water demand forecast based on the billing data, since the billing data shows the actual amount of water used and clear trends of water usage volume in each Khan are available.

Therefore, this study uses billing data to forecast water demand. However, it should be noted that the amount of water people currently consume is not necessarily equal to the amount of water they need, especially since the water production capacity in Phnom Penh has been insufficient in recent years. The water demand calculated use should be adjusted to take the lack of WTP capacity into consideration.

(2) Methodology of Water Demand Forecast

In order to use billing data for water demand forecasting, the same method must be applied to the previous water demand forecasts prepared in the Third Master Plan (M/P 2017) and compared in order to validate the method. As the results of the review of the previous water demand, which is shown in "**3.2.1 (1) Comparison of Past Water Demand Forecasts**", the following issues/characteristics were observed:

- Most of the forecasts have the same trends as the billing data.
- Some of the forecasts are different from the billing data.
- In Sangkats with a large number of connections, billing trends are clear, and forecasts tend to be reliable.
- In Sangkats with a small number of connections, billing trends are less clear, and forecasts tend to be unreliable.

Considering the above, the method can be useful if the issue of unreliable trends in Sangkats with a small number of connections can be solved. In order to solve the issue, it is desirable to forecast using a sufficient number of connections for each area. Therefore, the water demand forecast will be carried out by the same method used in the Third Master Plan (M/P 2017) at the Khan level. Large-scale development projects were not considered for water demand forecasting in the Third Master Plan (M/P 2017). However, such projects can have large impacts on the surround community and water usage patterns. Therefore, they will be included as one factor of water demand forecasting.

4.2.2 Application of Trend Method

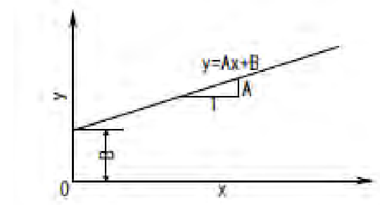
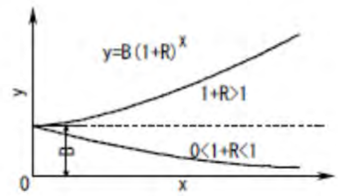
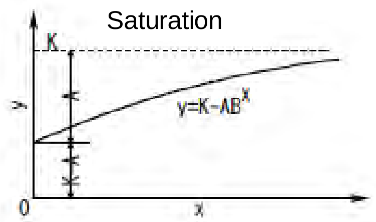
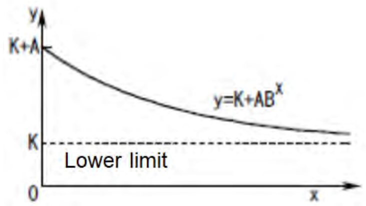
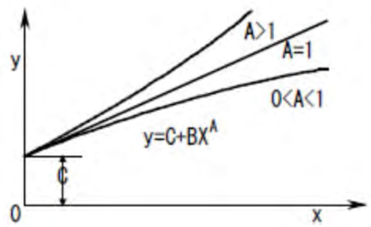
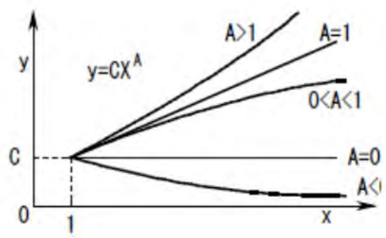
The applied methodology for the water demand forecast will use the following parameters:

- Connections per hectare.

- LPCD[1] (domestic).
- LPCD (non-domestic).
- Connection rate (domestic).

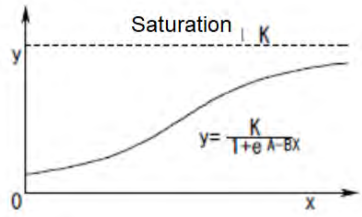
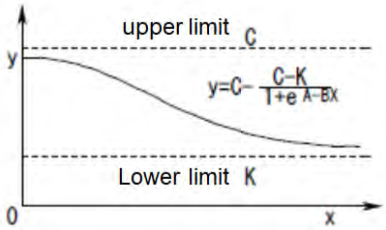
Future trends of these parameters need to be forecast based on the past trends. When the forecasting is carried out, the trend formulas shown in ***Table 4.2.1*** will be applied.

Table 4.2.1 Trend Formula to Forecast Future Trend of Each Parameter

NO	ITEM	DESCRIPTION	FIGURE
1	Name of Formula	Annual average increase/decrease formula	
	Formula	$y = Ax + B$	
	Characteristics	Increase / decrease in same	
	Application case	Increase / decrease in a linear manner	
2	Name of Formula	Annual average rate of increase / decrease formula	
	Formula	$y = B\ (1+R)^x$	
	Characteristics	Same Increase / decrease ratio is continued	
	Application case	Same increase / decrease ratio is continued for a long period	
3	Name of Formula	Modified exponential curve formula	
	Formula	$y = K - AB^x$	
	Characteristics	Upward asymptote toward saturation value K	
	Application case	In case of increase trend	
4	Name of Formula	Inverse modified exponential curve formula	
	Formula	$Y = K + AB^x$	
	Characteristics	Downward asymptote toward saturation value K	
	Application case	In case of decrease trend	
5	Name of Formula	Power curve formula	
	Formula	$Y = C + Bx^A$	
	Characteristics	Continuous increase Rate of change is increased over time	
	Application case	In case of continuous increase and rate of change is increased continuously	
6	Name of Formula	Modified power curve formula	
	Formula	$Y = Cx^A$	
	Characteristics	Continuous increase / decrease Rate of change is increased / decreased over time	
	Application case	In case of continuous increase / decrease and rate of change is increased / decreased continuously	
7	Name of Formula	Logistic curve formula	
	Formula	$y = \dfrac{K}{1 + e^{A-Bx}}$	

[1] liter per connection per day

Table 4.2.1 Trend Formula to Forecast Future Trend of Each Parameter

NO	ITEM	DESCRIPTION	FIGURE
	Characteristics	Gradual increase Intermediate increase ratio is highest, then the increase ratio is down Saturation after infinite year	
	Application case	In case of increase trend	
8	Name of Formula	Inverse logistic curve formula	
	Formula	$y = C - \frac{C-K}{1+e^{A-Bx}}$	
	Characteristics	Gradual decrease Intermediate decrease ratio is highest, then the decrease ratio is down Saturation after infinite year	
	Application case	In case of decrease trend	

Source: Design Criteria for Waterworks Facilities (2012) published by Japan Water Works Association (JWWA)

The appropriate formula will be selected based on the following conditions.

Table 4.2.2 Items to be considered to select an appropriate formula

ITEM	DESCRIPTION
Correlation coefficient	When correlation coefficient is more than 0.7, the relationship between past data and forecast data are considered significant.
Recent trend	There are 11 years of data, from 2010 to 2020. Based on these data, future trends are forecast. The trend is not consistent during the 11 years. For example, the first 5-6 years show high increases and the latter 5-6 years show only slight increases. In such cases, the trend observed in the latter 5 years will be prioritized, as shown in ***Figure 4.3.1***.
Situation of development	The future trends depend on the remaining areas of future development. Therefore, the areas for future development were studied and are shown below (Details are shown in ***Figure 4.1.2***, ***Figure 4.1.3***, ***Figure 4.3.2***, ***Figure 4.3.3*** and ***Figure 4.3.4***)
Expected changes in future	Considering the trend especially for the latter 5 years, future changes would be expected. If there is any other important information to forecast future trend, such information will also be considered.
Others	If there is any other information to forecast future situations, necessary information will be considered.

Source: JICA Data Collection Survey Team

4.3 WATER DEMAND FORECAST

4.3.1 Connections Per Hectare (Connections/ha)

The number of connections per hectare is forecast by the application of the trend formulas as shown in ***Table 4.2.1***. The suitable formula is selected for future trends with comprehensive considerations of the items as shown in ***Table 4.3.1***.

Table 4.3.1 Items to be Considered for the Selection of Suitable Formula

NO	ITEM	DESCRIPTION
a	Correlation coefficient	When correlation coefficient is more than 0.7, the relationship between past data and forecast data are considered significant.
b	Recent trend	There are data from 2010 to 2020. Based on these data, future trends are forecast. The trend is not consistent during the 11 years. For example, the first 5-6 years show high increase and the latter 5-6 years show low increases. In such cases, the trend observed in the latter 5 years will be prioritized, as shown in ***Figure 4.3.1***.
c	Situation of development	The future trends depend on the remaining area for future development. Therefore, the areas for future development were studied and are shown below (Details are shown in ***Figure 4.1.2***, ***Figure 4.1.3***, ***Table 4.3.2***, ***Table 4.3.3***, and ***Table 4.3.4***)
d	Expected changes in future	Considering the trend, especially for the latter 5 years, future changes would be expected. If there is any other important information to forecast future trend, such information will also be considered.
e	Others	If there is any other information to forecast future situations, necessary information will be considered.

Note: The contents of the table are same as ***Table 4.2.2***
Source: JICA Data Collection Survey Team

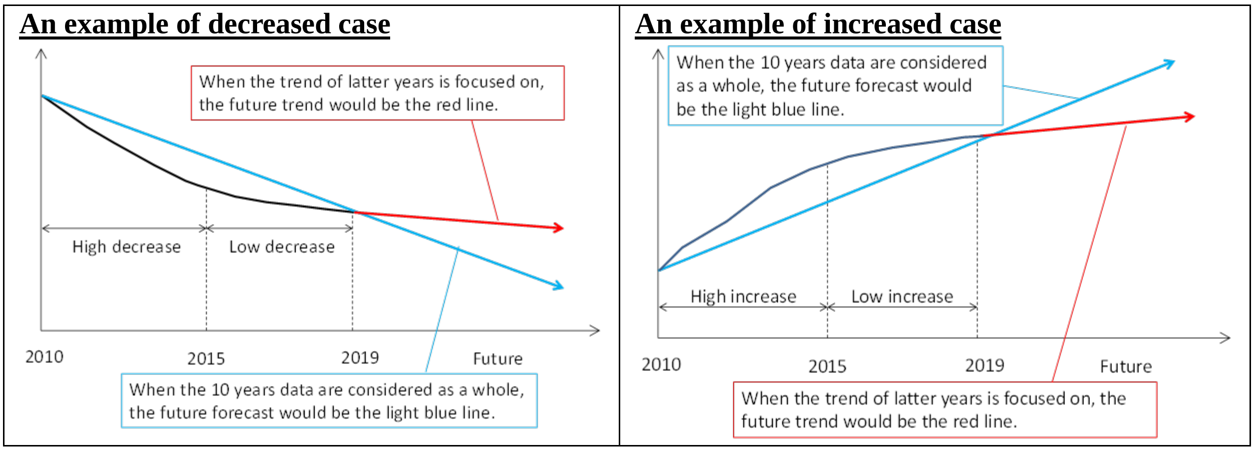


Figure 4.3.1 Importance to Consider the Recent Trend (Schematic)
Source: JICA Data Collection Survey Team

Future developments are studied mainly based on the land use plan shown in ***Figure 4.3.2*** and current development situations. The example of the current development situation in Khan Russey Keo is as shown in ***Figure 4.3.3***.

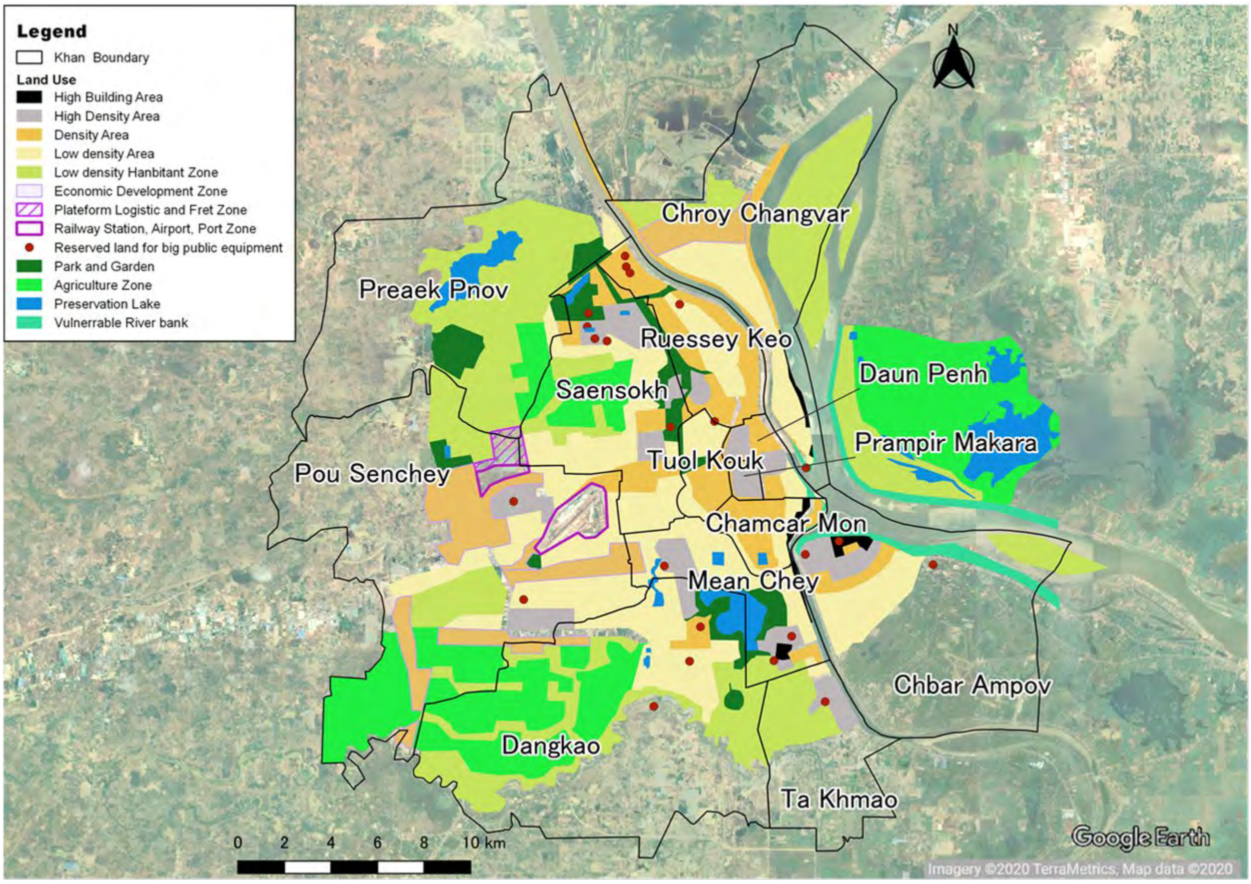


Figure 4.3.2 Land Use Master Plan of Phnom Penh City 2035

Source: Land Use Master Plan of Phnom Penh City 2035

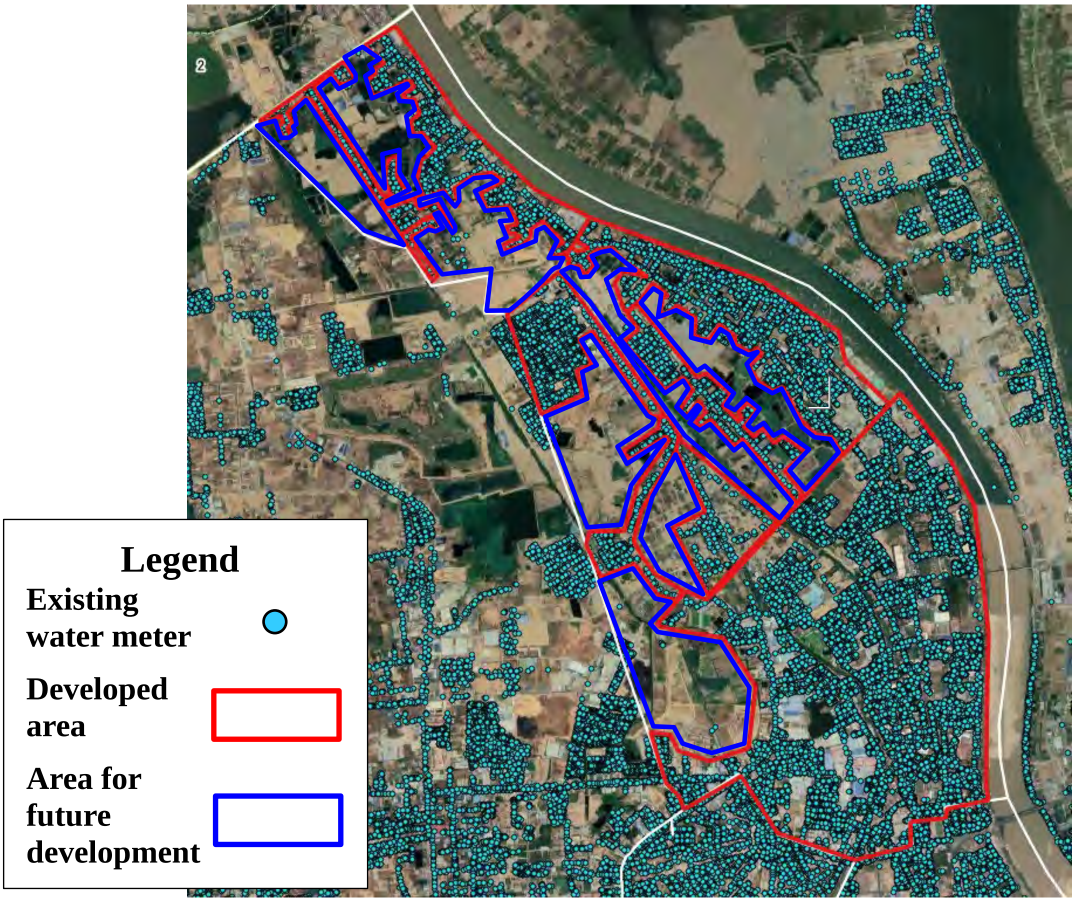


Figure 4.3.3 Example of Development Limit

Source: Google map and GIS data from PPWSA

Based on the development situation obtained from ***Figure 4.3.3***, the development limit in Khan Mean Chey is calculated as shown in***Table 4.3.2***.

Considering land availability for the next 10 years, all Khans are classified as either a "Developed area", "Developing area with limited future area", or "Developing area with enough future area", as shown in ***Table 4.3.3***.

Based on these classifications, the Khan Russey Keo, Mean Chey and Saensokh need to consider the development limit, as shown in ***Table 4.3.4***.

Table 4.3.2 Development Limit in Case of Khan Mean Chey

NO	ITEM	UNIT	HOW TO CALCULATE	RUSSEY KEO
1	Current connections/ha (Developed area)	Connections/ha	From GIS data	22.6
2	Area for future development	ha	From GIS data	636
3	Connections/ha (Area for future development)	Connections/ha	Same condition with No.1	22.6
4	Maximum connection number (Area for future development)	Connection	No.2 x No.3	14,362
5	Connection number (Developed area)	Connection	From billing data	34,442
6	Maximum connection number in target Khans	Connection	No.4 + No.5	48,804
7	Entire area (target Khan)	ha	From GIS data	2,481
8	Assumed connections/ha	Connections/ha	No.6 ÷ No.7	19.7
9	Maximum connections/ha	Connections/ha	No.8 x 1.1	21.6

Source: JICA Data Collection Survey Team

Table 4.3.3 Classification of Khan

GROUP	DESCRIPTION	TARGET KHAN
Developed area	The areas have already been developed and there is no area for future development. However, redevelopment is possible.	Daun Penh, Prampir Makara, Chamkar Mon, Tuol Kouk
Developing area with limited future area	All areas claimed for development and there is limited area for future development in the next 10 years. Development limit as shown in ***Table 4.3.2*** should be considered.	Russey Keo, Mean Chey, Saensokh
Developing area with enough future area	The areas are under development and there are enough areas for future development. It is no need to consider the development limit.	Dangkao, Pou Senchey, Chroy Changvar, Chbar Ampov, Preaek Pnov, Ta Khmau

Source: JICA Data Collection Survey Team

Table 4.3.4 Development Limit of the Concerned Khans

NO	ITEM	UNIT	RUSSEY KEO	MEAN CHEY	SAENSOKH
1	Current connections/ha (Developed area)	Connections/ha	22.6	27.9	16.9
2	Area for future development	ha	636	500	1,192
3	Connections/ha (Area for future development)	Connections/ha	22.6	27.9	16.9
4	Maximum connection number (Area for future development)	Connection	14,362	13,950	20,132
5	Connection number (Developed area)	Connection	34,442	44,595	49,077
6	Maximum connection number in target Khans	Connection	48,804	58,545	69,209
7	Entire area (target Khan)	ha	2,481	1,598	5,173
8	Assumed connections/ha	Connections/ha	19.7	23.3	13.4
9	Maximum connections/ha	Connections/ha	21.6	25.6	14.7

Source: JICA Data Collection Survey Team

Considering the above descriptions, the actual selection of the suitable trend formula in Khan Mean Chey is shown in next page as one example. The selections in other Khans are shown in ***Appendix***.

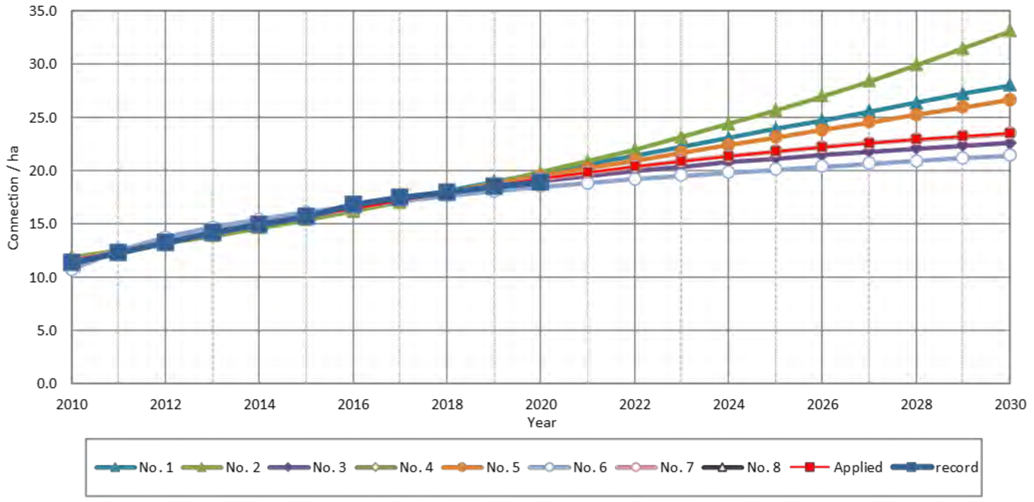
06 Mean Chey Unit : Connection / ha

Year	Actual record	Formula* No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	Application No. 7
2010	11.34	11.52	11.89	11.22	N/A	11.34	10.70	11.59	N/A	11.59
2011	12.30	12.34	12.52	12.30	N/A	12.35	12.53	12.42	N/A	12.42
2012	13.24	13.17	13.18	13.30	N/A	13.23	13.74	13.24	N/A	13.24
2013	14.13	13.99	13.87	14.23	N/A	14.07	14.67	14.07	N/A	14.07
2014	14.97	14.82	14.60	15.08	N/A	14.88	15.43	14.88	N/A	14.88
2015	15.72	15.65	15.37	15.87	N/A	15.68	16.09	15.68	N/A	15.68
2016	16.78	16.47	16.17	16.60	N/A	16.46	16.66	16.45	N/A	16.45
2017	17.45	17.30	17.02	17.28	N/A	17.23	17.17	17.20	N/A	17.20
2018	17.94	18.12	17.92	17.90	N/A	17.99	17.64	17.91	N/A	17.91
2019	18.55	18.95	18.86	18.48	N/A	18.74	18.07	18.59	N/A	18.59
2020	18.86	19.78	19.85	19.02	N/A	19.49	18.47	19.22	N/A	19.22
2021		20.60	20.90	19.51	N/A	20.22	18.84	19.82	N/A	19.82
2022		21.43	21.99	19.97	N/A	20.95	19.18	20.38	N/A	20.38
2023		22.26	23.15	20.39	N/A	21.68	19.51	20.90	N/A	20.90
2024		23.08	24.37	20.78	N/A	22.40	19.82	21.37	N/A	21.37
2025		23.91	25.65	21.14	N/A	23.11	20.11	21.81	N/A	21.81
2026		24.73	27.00	21.48	N/A	23.83	20.39	22.21	N/A	22.21
2027		25.56	28.41	21.79	N/A	24.53	20.66	22.57	N/A	22.57
2028		26.39	29.91	22.08	N/A	25.24	20.91	22.90	N/A	22.90
2029		27.21	31.48	22.34	N/A	25.93	21.16	23.20	N/A	23.20
2030		28.04	33.13	22.59	N/A	26.63	21.40	23.47	N/A	23.47

		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Coefficient	A	1	—	16	N/A	0.909	0.228	0.319	N/A
	B	11	11	0.925	N/A	1.005	—	0.129	N/A
	C	—	—	—	—	11	10.7	—	N/A
	R	—	0.053	—	—	—	—	—	—
	K	—	—	25.60	N/A	—	—	25.60	N/A
Correlation coefficient		0.99269	0.98320	0.9988	N/A	0.9962	0.98630	0.9970	N/A

Satulation value (K)

Formula No	Calculation	Validity	Applied	Reason
3	47.91	NG	25.60	Based on the development limit
7	25.14	-	25.60	Based on the development limit

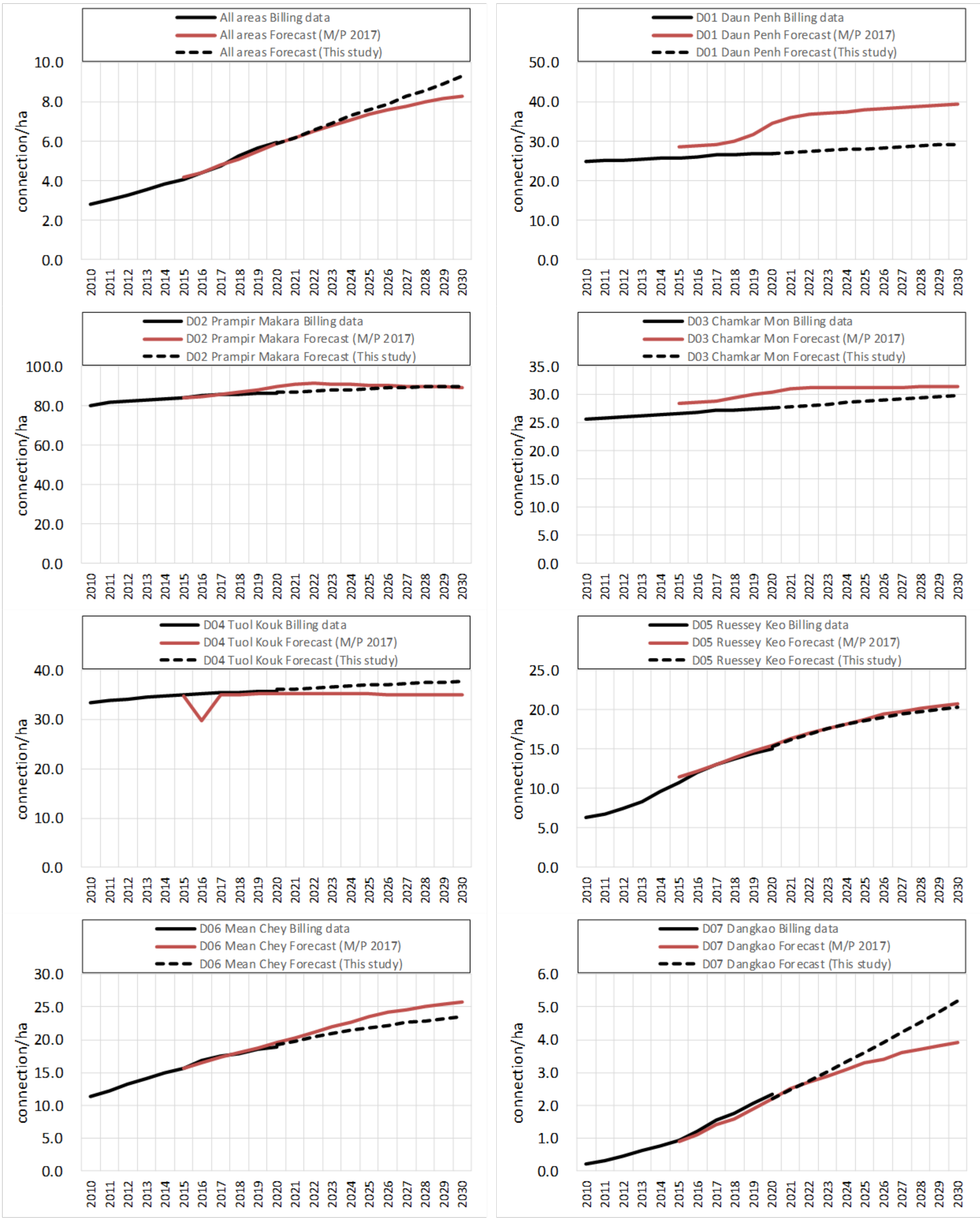


No	Item	Description	Applicable formula
a	Correlation coefficient: 0.70 or more	-	No. 1,2,3,5,6,7
b	Recent trend	Increasing	No. 1,2,3,6,7
c	Situation of development	The current connection / ha is approx. 18 and the maximum value was estimated as 25.6 connection / ha.	-
d	Expected changes in future	The development limit (25.6 connection / ha) should be considered.	No. 3,6,7
e	Others	-	-

Applied formula	Reason	Remarks
No. 7	Connection / ha would reach the saturation around 25.6 connection / ha. Therefore, No.7 is appropriate.	-

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA:

The number of connections per hectare in the future was forecast based on the above method and the results of the forecasts for all of Khans are shown below.



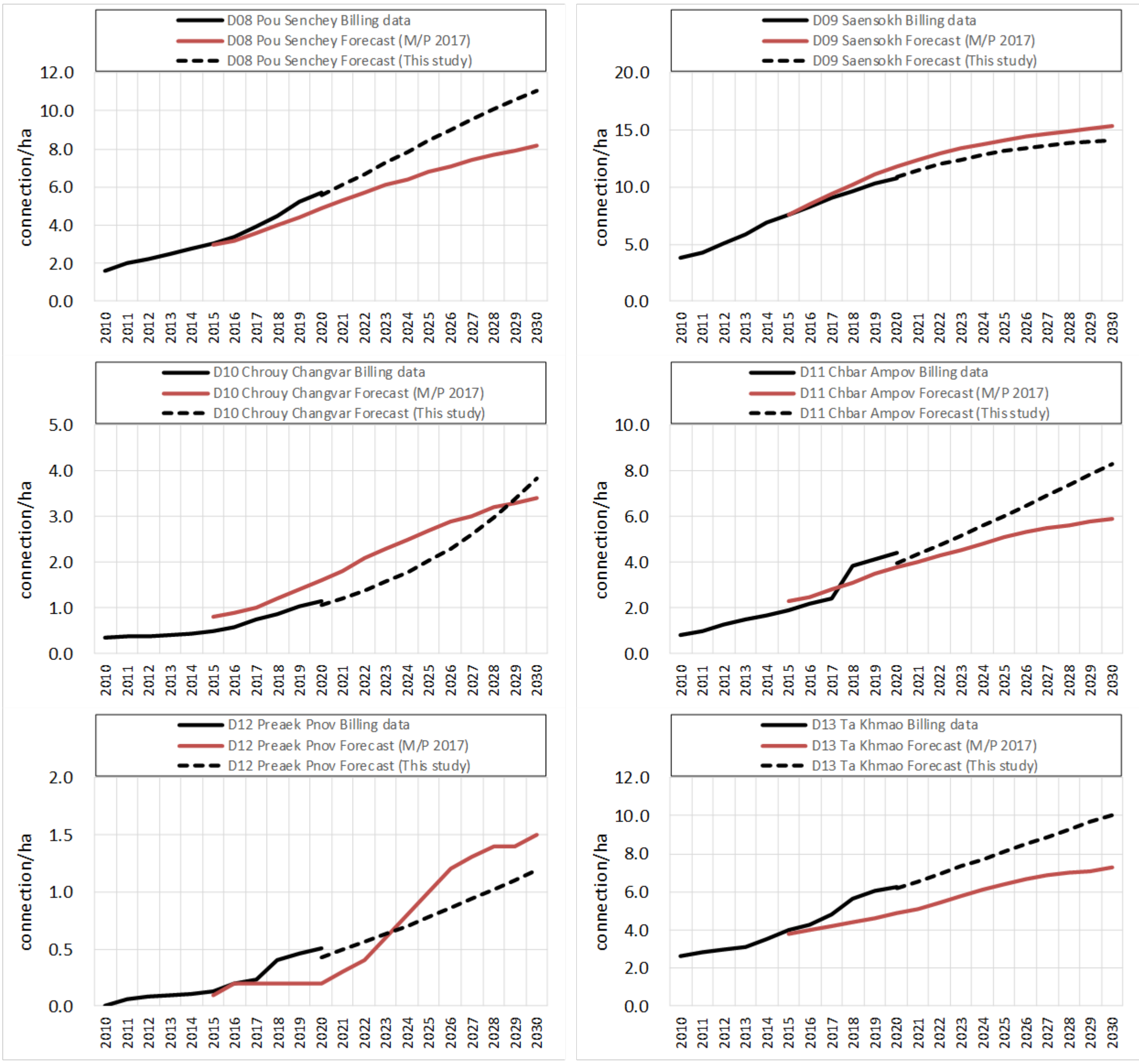


Figure 4.3.4 Results of the Forecasts on Connections per hectare for All The Khans

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

4.3.2 Domestic Connection Rate

The domestic connection rate is forecast by the application of the trend formulas as shown in ***Table 4.2.1***. The suitable formula is selected for future trends with comprehensive consideration of the items shown in ***Table 4.3.5***.

Table 4.3.5 Items to consider the selection of suitable formula

NO	ITEM	DESCRIPTION
A	Correlation coefficient	When correlation coefficient is more than 0.7, the relationship between past data and forecast data are considered significant.
b	Recent trend	There are past ten years data from 2010 to 2019. Based on these data, future trends are forecast. The trend is not consistent during the 11 years. For example, the first 5-6 years show high increase and the latter 5-6 years show low increases. In such cases, the trend observed in the latter 5 years will be prioritized, as shown in ***Figure 4.3.1***.
c	Expected changes in future	Considering the trend especially for the latter 5 years, future changes would be expected. If there is any other important information to forecast future trend, such information will also be considered.
d	Others	If there is any other information to forecast future situations, necessary information will be considered.

Note: The contents of the table are same as ***Table 4.2.2*** except for "Situation of development".
Source: JICA Data Collection Survey Team

The actual selection of the suitable trend formula for Khan Mean Chey shown below is one example of the method. The details for other Khans are shown in ***Appendix***.

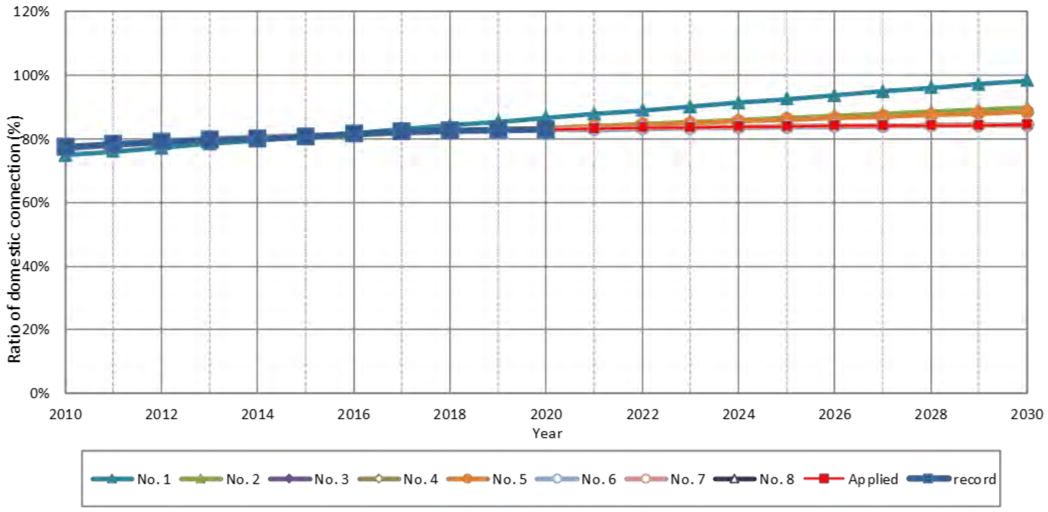
06 Mean Chey — Unit : Ratio of domestic connection

Year	Actual record	Formula*								Application
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 7
2010	0.774	0.748	0.778	0.770	N/A	0.774	0.767	0.770	N/A	0.770
2011	0.782	0.760	0.783	0.780	N/A	0.782	0.783	0.780	N/A	0.780
2012	0.789	0.772	0.789	0.789	N/A	0.789	0.793	0.789	N/A	0.789
2013	0.795	0.783	0.794	0.797	N/A	0.795	0.801	0.797	N/A	0.797
2014	0.801	0.795	0.800	0.804	N/A	0.801	0.806	0.804	N/A	0.804
2015	0.807	0.807	0.806	0.810	N/A	0.807	0.811	0.810	N/A	0.810
2016	0.816	0.819	0.812	0.815	N/A	0.813	0.815	0.815	N/A	0.815
2017	0.821	0.831	0.817	0.820	N/A	0.818	0.818	0.820	N/A	0.820
2018	0.824	0.842	0.823	0.824	N/A	0.824	0.821	0.824	N/A	0.824
2019	0.828	0.854	0.829	0.827	N/A	0.829	0.824	0.827	N/A	0.827
2020	0.829	0.866	0.835	0.830	N/A	0.834	0.826	0.830	N/A	0.830
2021		0.878	0.841	0.832	N/A	0.840	0.829	0.832	N/A	0.832
2022		0.890	0.847	0.834	N/A	0.845	0.831	0.834	N/A	0.834
2023		0.901	0.853	0.836	N/A	0.850	0.833	0.836	N/A	0.836
2024		0.913	0.859	0.838	N/A	0.855	0.834	0.838	N/A	0.838
2025		0.925	0.865	0.839	N/A	0.860	0.836	0.839	N/A	0.839
2026		0.937	0.872	0.840	N/A	0.865	0.838	0.840	N/A	0.840
2027		0.949	0.878	0.841	N/A	0.870	0.839	0.841	N/A	0.841
2028		0.960	0.884	0.842	N/A	0.874	0.841	0.842	N/A	0.842
2029		0.972	0.890	0.843	N/A	0.879	0.842	0.843	N/A	0.843
2030		0.984	0.897	0.844	N/A	0.884	0.843	0.843	N/A	0.843

		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Coefficient	A	0	—	0	N/A	0.868	0.031	-2.145	N/A
	B	1	1	0.865	N/A	0.008	—	0.157	N/A
	C	—	—	—	—	1	0.8	—	N/A
	R	—	0.007	—	—	—	—	—	—
	K	—	—	0.848	N/A	—	—	0.847	N/A
Correlation coefficient		0.98783	0.98803	0.9936	N/A	0.9939	0.97387	0.9942	N/A

Satulation value (K)

Formula No	Calculation	Validity	Applied	Reason
3	0.848	OK	0.848	
7	0.847	OK	0.847	



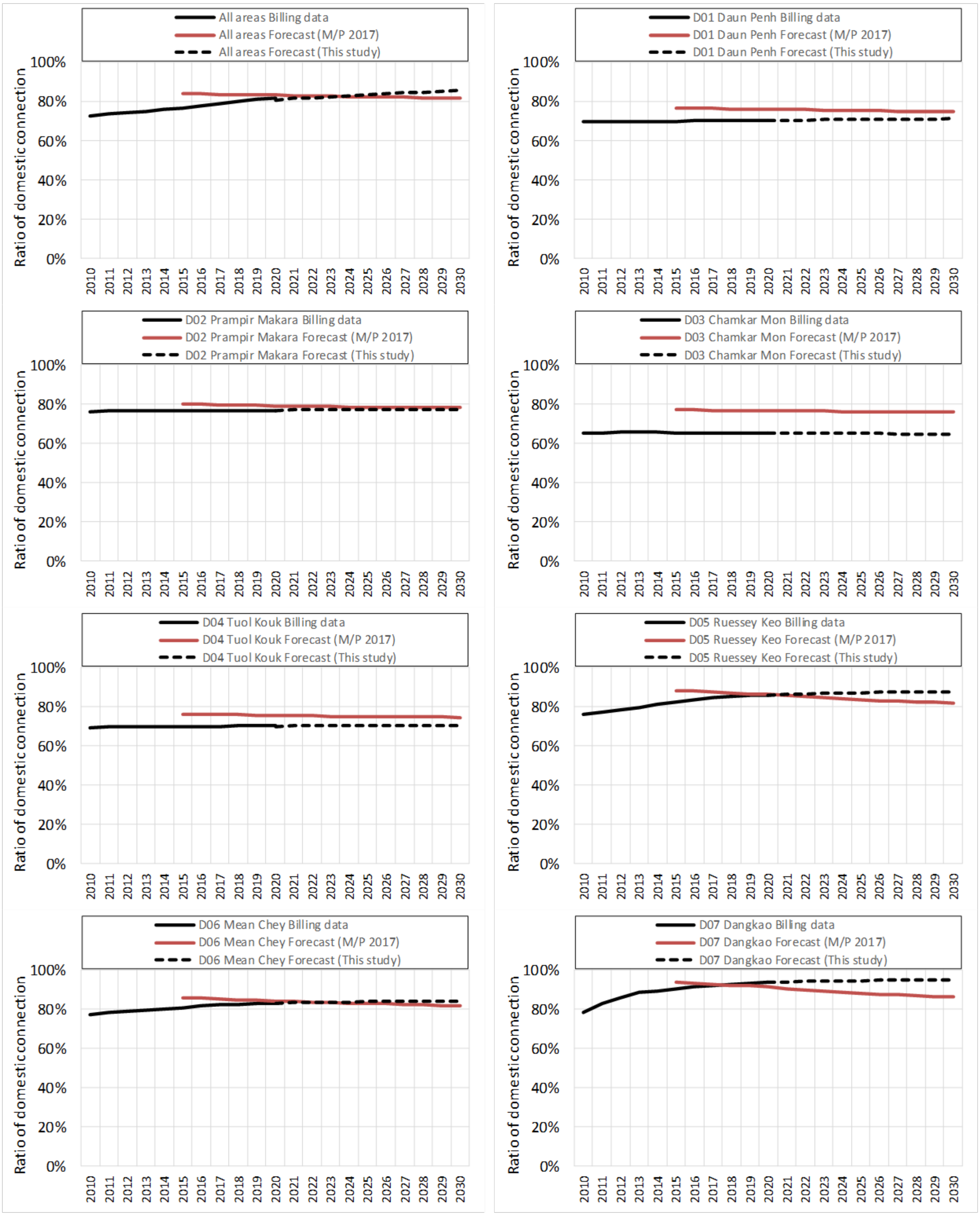
No	Item	Description	Applicable formula
a	Correlation coefficient: 0.70 or more	-	No. 1,2,3,5,6,7
b	Recent trend	Increasing from 2010 to 2018, and almost constant from 2018 to 2020	No. 3,6,7
c	Expected changes in future	The trend is in a atable in recently. The stable situation would be continued.	No. 3,6,7
d	Others	-	-

Applied formula	Reason	Remarks
No.7	No.3,6,7 are almost same. No.7 is selected, since the correlation coefficient is the highest.	-

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA:

Based on the above method, the future forecast of the domestic connection rate is calculated. The results of the forecast for all of the Khans are shown below.

The future domestic connection rate was forecast based on the method above, and the results for all of the Khans are shown as below.



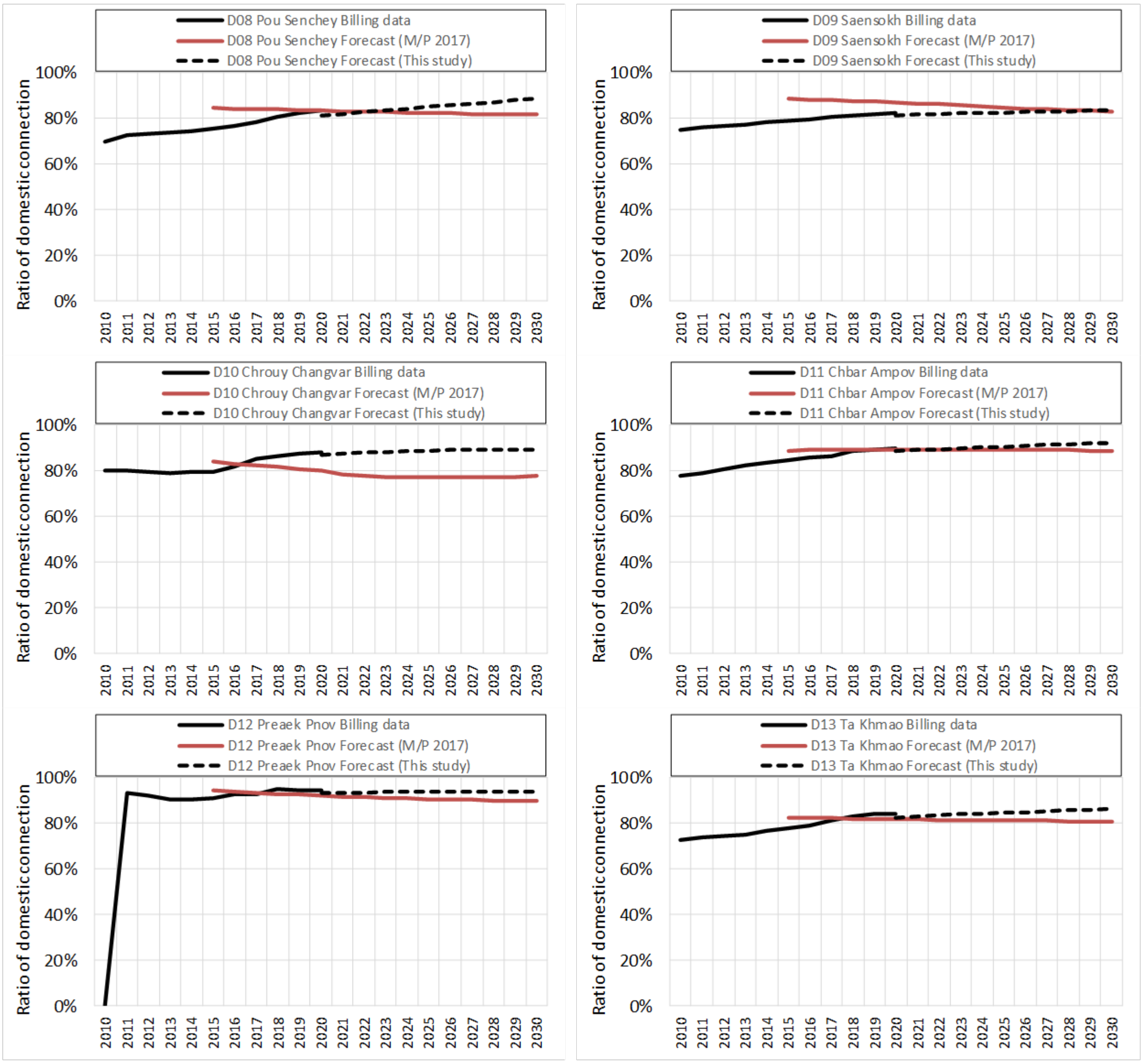


Figure 4.3.5 Results of the Forecasts on Percent of Domestic Connection for All The Khans

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

4.3.3 LPCD

The LPCD applied in past master plans is shown in ***Table 4.3.6***. LPCD was investigated in the Second Master Plan (M/P 2006) and consumption per connection was calculated by multiplying the LPCD by the average number of people per household. It is observed that LPCD is increasing every time the past master plan is updated.

Table 4.3.6 Comparison of Consumption Per Connection (Domestic)

Unit: m^3/day/connection

M/P	2005	2010	2012	2015	2018	2020	2030
M/P 2006	0.45	0.48	0.50	0.53	0.56	0.58	-
M/P 2013	-	-	0.91	-	0.91	-	-
M/P 2017	-	-	-	0.95	0.976	0.994	1.03

Source: M/P 2006, M/P 2013, M/P 2017

The actual LPCD by each Khan is shown in ***Figure 4.3.6***

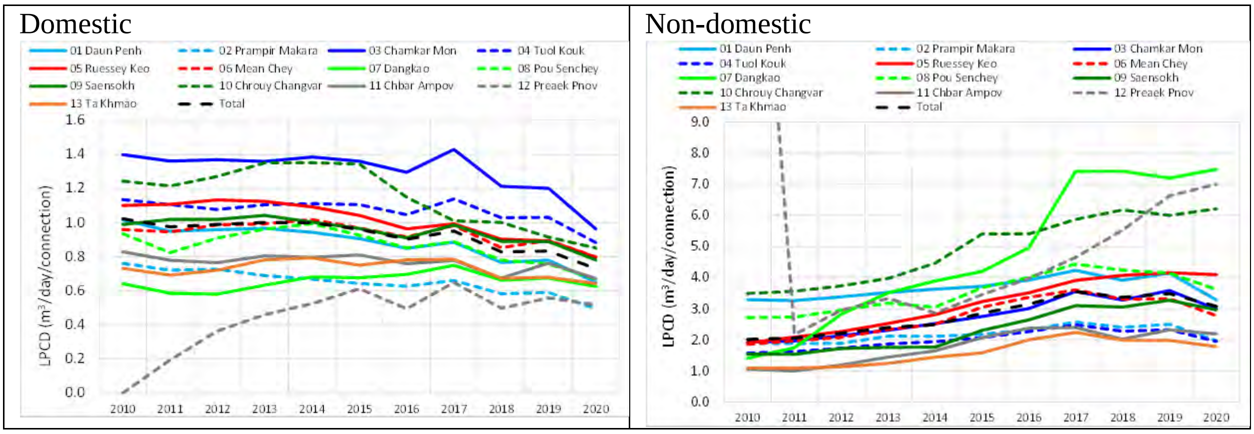


Figure 4.3.6 LPCD in each Khan from 2010 to 2020

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

There are large differences in consumption among Khans, as shown in the above ***Figure 4.3.6***. In case of domestic connections, it is assumed that the differences come from the difference of number of people per household. Therefore, comparisons of LPCD and the person number per household were implemented, as shown in ***Table 4.3.7*** and ***Table 4.3.7***.

Table 4.3.7 Comparisons of Lpcd and Person Number Per Household

Khan	LPCD (2019)[1)] m^3/day/connection	Persons per family[2)]	Persons per family[3)]
01 Doun Penh	0.780	5.11	5.27
02 Prampir Meakkakra	0.590	5.21	4.69
03 Chamkar Mon	1.201	5.30	4.69
04 Tuol Kouk	1.030	5.25	4.92
05 Ruessei Kaev	0.893	4.40	4.55
06 Mean Chey	0.895	4.92	4.31
07 Dangkao	0.674	4.56	4.56
08 Pou Saenchey	0.757	5.56	3.64
09 Saensokh	0.888	4.85	4.53
10 Chrouy Changvar	0.915	4.59	5.08
11 Chhbar Ampov	0.762	4.73	4.75
12 Preaek Phnov	0.558	4.61	4.73
13 Ta Khmau	0.679	4.81	4.53
Total	0.833	4.93	4.57

1) Billing data
2) CDB data: National Institute of Statistics Population (NIS)
3) Census 2019
Source: JICA Data Collection Survey Team

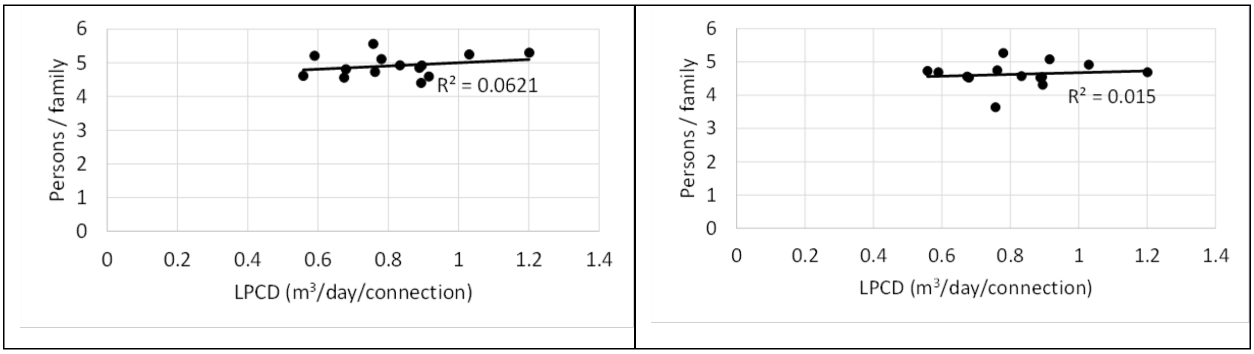


Figure 4.3.7 Comparisons of LPCD and Person Number Per Household

Source: Prepared by JICA Data Collection Survey Team based on the NIS and billing data

The following are observed from the comparison of LPCD and number of people per household:

- There are no clear relations between LPCD and number of people per household.

According to the discussions with PPWSA on this issue, the following situations were pointed out to explain the nature of the relationship between LPCD and number of people per household:

- There are cases that a many people use one connection in one apartment or house.
- There may be cases that the actual number of people in one household is not reflected accurately in the population data.

Based on the above information, it is not realistic to consider LPCD from the number of people per household extracted from population data. It is better to consider the trend of each Khan. This can be applied not only to domestic connections, but also to non-domestic connections. Therefore, the LPCD forecasts were carried out based on the application of the trend formula.

(1) Basic Idea to Forecast LPCD

Average LPCD for domestic category in Phnom Penh is shown in ***Figure 4.3.8***.

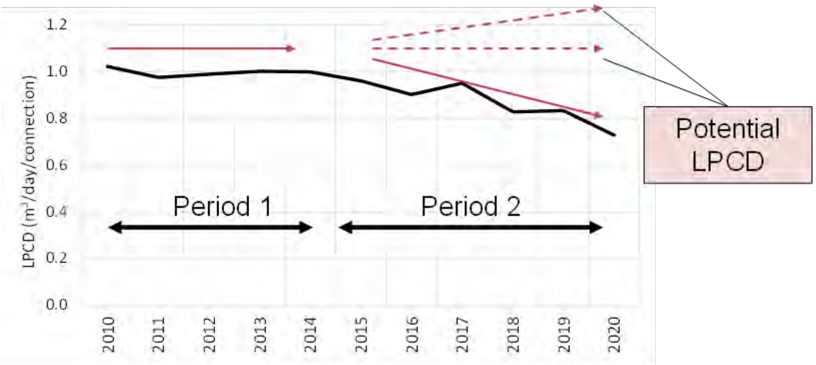


Figure 4.3.8 Average LPCD (Domestic)

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

The domestic LPCD is stable until 2014. However, the LPCD decreased drastically after 2014. The decrease is attributed to the lack of water production capacity. Operation rate of WTPs during Period 1 was under 100% and increased to more than 100% during Period 2. Therefore, the following are assumed:

- People could use as much water as they need during Period 1.
- The amount of water people could use was limited during Period 2.

If the production capacities of the WTPs were sufficient, the LPCD should be higher than the current level, as shown in ***Figure 4.3.8***. Therefore, the potential LPCD must be considered for the water demand forecast.

The average LPCD for non-domestic category in Phnom Penh is shown in ***Figure 4.3.9***. In spite of the lack of WTPs capacity, non-domestic LPCD shows increasing trends, except for 2020. The decrease in 2020 is caused by the effect of the COVID-19. The following factors are assumed for the increase trend of non-domestic LPCD in spite of the situation of lack of WTPs capacity:

- Non-domestic customers are equipped with suction pumps and large tanks to obtain and store water effectively.
- Non-domestic customers store/use water at midnight.

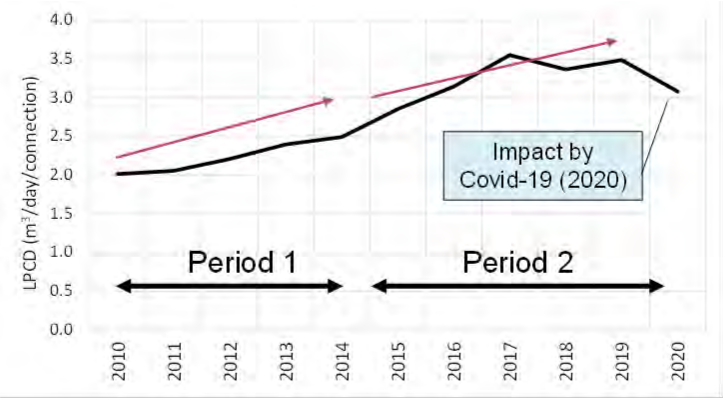


Figure 4.3.9 Average LPCD (Non-Domestic)
Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

(2) LPCD for Domestic Connection

The LPCD for domestic connection is forecast by the application of the trend formulas shown in ***Table 4.2.1***. The suitable formula is selected for future trends with comprehensive consideration of the items shown in ***Table 4.3.8***.

Table 4.3.8 Items to be Considered for the Selection of Suitable Formula

NO	ITEM	DESCRIPTION
a	Correlation coefficient	When correlation coefficient is more than 0.7, the relationship between past data and forecast data are considered significant.
b	Trend (2010-2014, Period 1)	Situations shown in ***Table 4.3.8*** and ***Table 4.3.9*** are confirmed.
c	Trend (2014-2019, Period 2)	Ditto
c	Expected changes in future	The expected changes in future are described mainly based on the trend of the Period 1 and Period 2. If there is any other important information to forecast future trend, such information will also be considered.
d	Others	If there is any other information to forecast future situations, necessary information will be considered.

Source: JICA Data Collection Survey Team:

The actual selection of the suitable trend formula in Khan Daun Penh is shown in next page as one example of the method. The details for other Khans are shown in ***Appendix***.

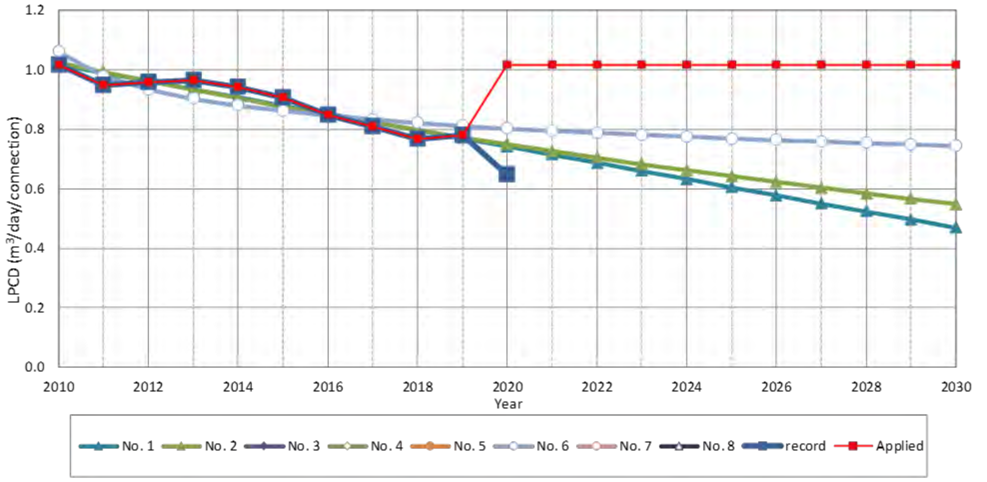
01 Daun Penh Unit : LPCD domestic (m^3/day/connection)

Year	Actual record	Formula*								Application
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	1.015
2010	1.015	1.018	1.024	N/A	N/A	1.015	1.061	N/A	N/A	1.015
2011	0.949	0.990	0.993	N/A	N/A	N/A	0.979	N/A	N/A	0.949
2012	0.958	0.963	0.962	N/A	N/A	N/A	0.934	N/A	N/A	0.958
2013	0.966	0.935	0.933	N/A	N/A	N/A	0.903	N/A	N/A	0.966
2014	0.942	0.908	0.904	N/A	N/A	N/A	0.880	N/A	N/A	0.942
2015	0.906	0.880	0.876	N/A	N/A	N/A	0.861	N/A	N/A	0.906
2016	0.849	0.853	0.849	N/A	N/A	N/A	0.846	N/A	N/A	0.849
2017	0.808	0.825	0.823	N/A	N/A	N/A	0.833	N/A	N/A	0.808
2018	0.766	0.798	0.798	N/A	N/A	N/A	0.822	N/A	N/A	0.766
2019	0.780	0.770	0.773	N/A	N/A	N/A	0.811	N/A	N/A	0.780
2020	0.649	0.743	0.750	N/A	N/A	N/A	0.803	N/A	N/A	1.015
2021		0.715	0.727	N/A	N/A	N/A	0.794	N/A	N/A	1.015
2022		0.688	0.704	N/A	N/A	N/A	0.787	N/A	N/A	1.015
2023		0.660	0.683	N/A	N/A	N/A	0.780	N/A	N/A	1.015
2024		0.633	0.662	N/A	N/A	N/A	0.774	N/A	N/A	1.015
2025		0.605	0.641	N/A	N/A	N/A	0.768	N/A	N/A	1.015
2026		0.578	0.622	N/A	N/A	N/A	0.763	N/A	N/A	1.015
2027		0.550	0.603	N/A	N/A	N/A	0.758	N/A	N/A	1.015
2028		0.523	0.584	N/A	N/A	N/A	0.753	N/A	N/A	1.015
2029		0.496	0.566	N/A	N/A	N/A	0.748	N/A	N/A	1.015
2030		0.468	0.549	N/A	N/A	N/A	0.744	N/A	N/A	1.015

Coefficient	A	0	—	N/A	N/A	N/A	-0.117	N/A	N/A
	B	1	1	N/A	N/A	N/A	—	N/A	N/A
	C	—	—	—	—	1	1.1	—	N/A
	R	—	-0.031	—	—	—	—	—	—
	K	—	—	N/A	N/A	—	—	N/A	N/A
Correlation coefficient		0.95555	0.94944	N/A	N/A	N/A	0.85795	N/A	N/A

Satulation value (K)

Formula No	Calculation	Validity	Applied	Reason
3	0.988	NG	N/A	
7	0.984	NG	N/A	

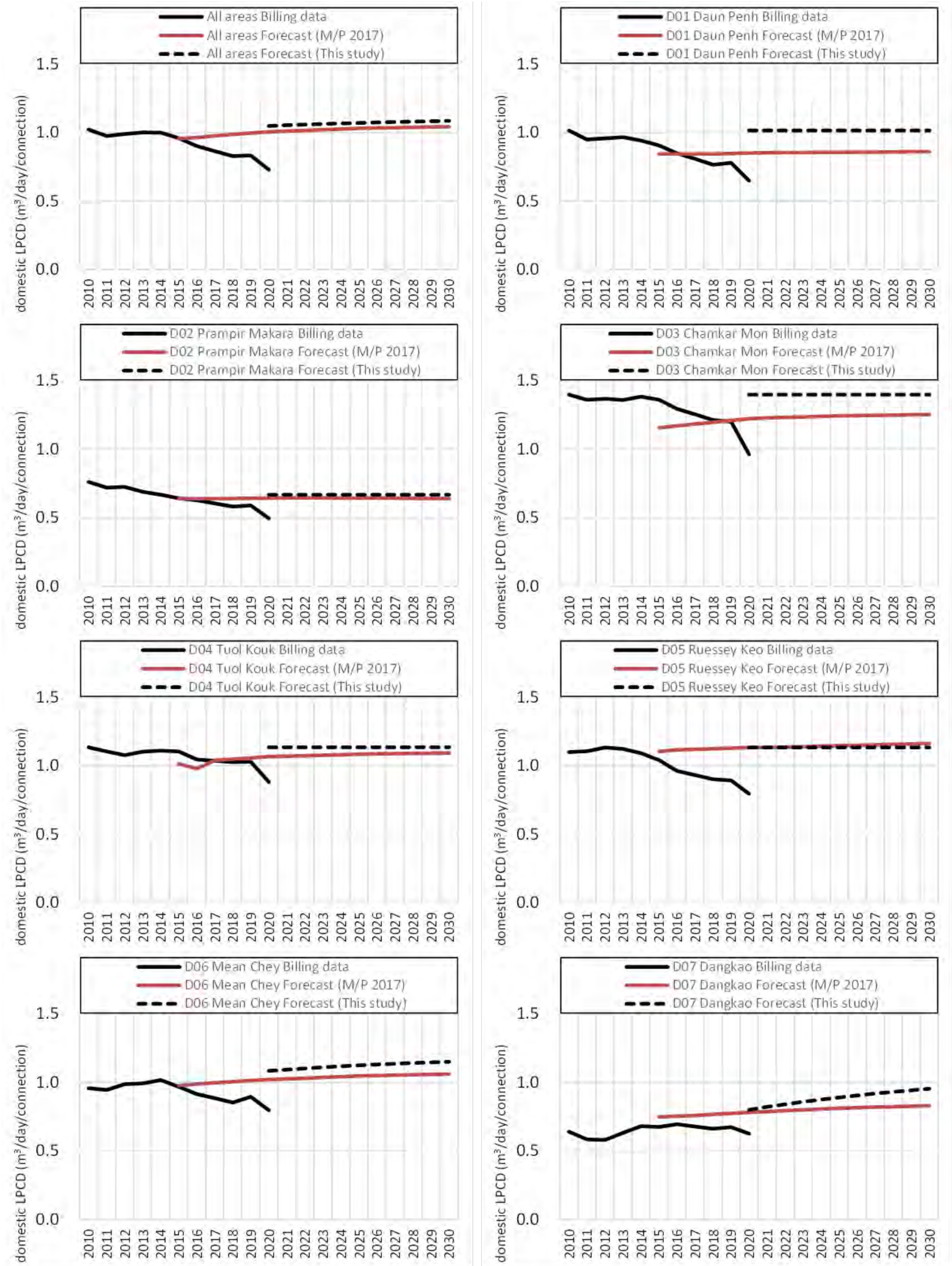


No	Item	Description	Applicable formula
a	Correlation coefficient: 0.70 or more	-	No.1,2,6
b	Trend (2010 - 2014, Period 1)	Stable	-
c	Trend (2014 - 2019, Period 2)	Decreasing; The decreasing trend is supposed to be coming from lack of water supply.	-
d	Expected changes in future	The trend should be considered from the situation of Period 1. The maximum value in the Period 1 seems to be appropriate, since the situation has been stable in the Period 1.	1.015
e	Others	-	-

Applied formula	Reason	Remarks
1.015	Same as the above "No. d"	-

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

The domestic LPCD in the future was forecast based on the above method, and the results for all of the Khans are shown below.



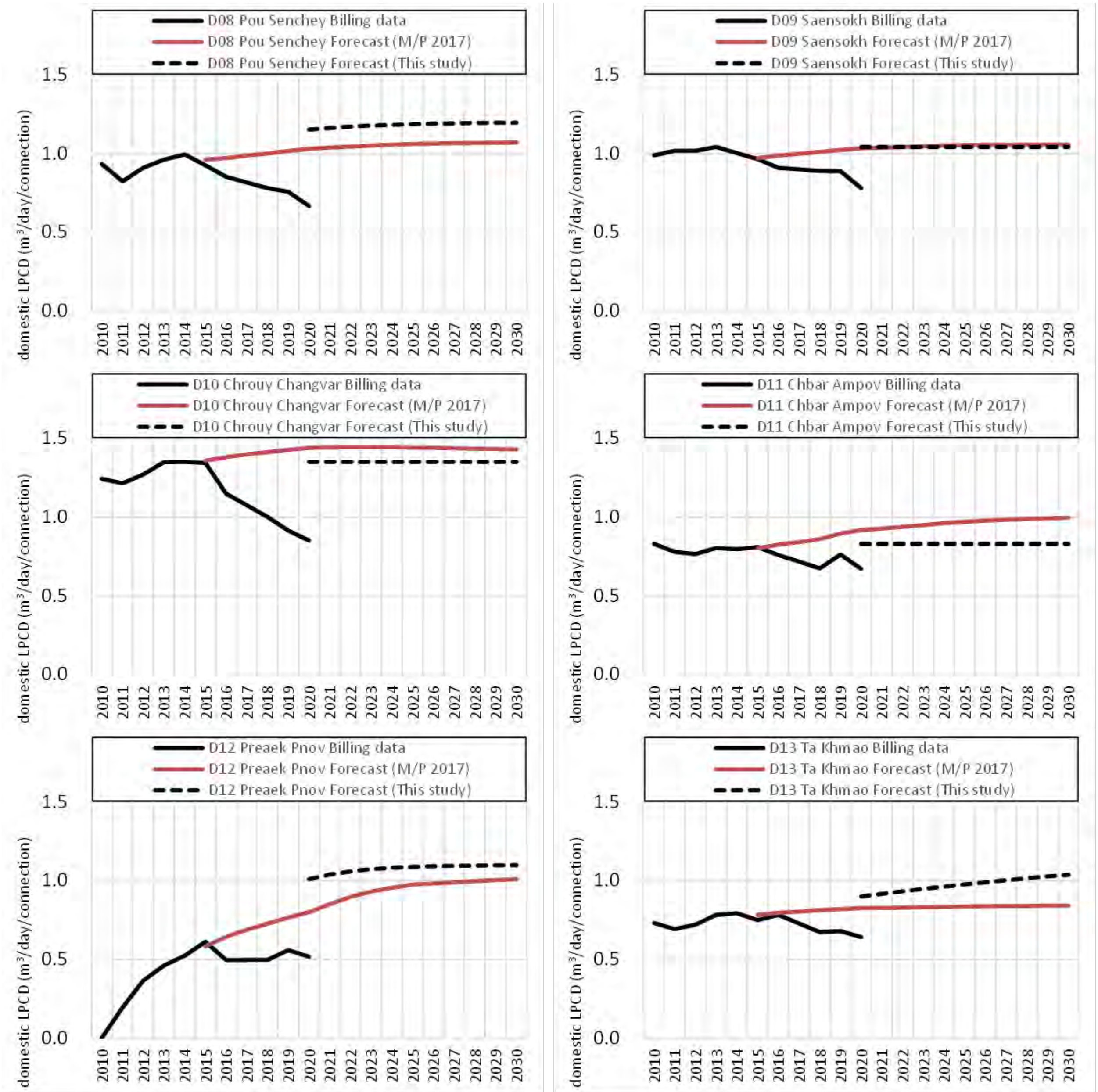


Figure 4.3.10 Results of the forecasts on domestic LPCD for all the Khans

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

(3) LPCD for Non-Domestic Connection

The LPCD for non-domestic connections is forecast by the application of the trend formulas shown in ***Table 4.2.1*** which is same method as the domestic LPCD. The suitable formula is selected for future trends considering the items shown in ***Table 4.3.8***.

The actual selection of the suitable trend formula in Khan Daun Penh is shown in the next page as one example of the method. The details for other Khans are shown in ***Appendix***.

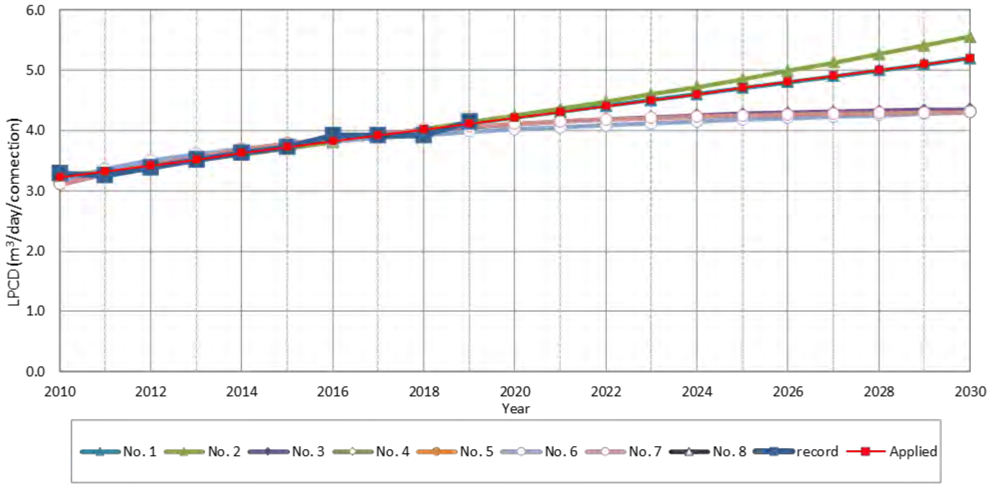
01 Daun Penh — Unit : LPCD non-domestic (m^3/day/connection)

Year	Actual record	Formula*								Application
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 1
2010	3.287	3.224	3.238	3.094	N/A	3.287	3.117	3.104	N/A	3.224
2011	3.259	3.322	3.327	3.273	N/A	N/A	3.354	3.272	N/A	3.322
2012	3.377	3.421	3.418	3.427	N/A	N/A	3.500	3.423	N/A	3.421
2013	3.521	3.520	3.511	3.561	N/A	N/A	3.609	3.558	N/A	3.520
2014	3.622	3.618	3.607	3.677	N/A	N/A	3.695	3.677	N/A	3.618
2015	3.717	3.717	3.706	3.778	N/A	N/A	3.767	3.780	N/A	3.717
2016	3.920	3.816	3.807	3.865	N/A	N/A	3.828	3.869	N/A	3.816
2017	3.916	3.914	3.911	3.940	N/A	N/A	3.883	3.945	N/A	3.914
2018	3.912	4.013	4.018	4.006	N/A	N/A	3.931	4.010	N/A	4.013
2019	4.145	4.112	4.128	4.062	N/A	N/A	3.975	4.064	N/A	4.112
2020	3.279	4.210	4.241	4.111	N/A	N/A	4.016	4.110	N/A	4.210
2021		4.309	4.357	4.154	N/A	N/A	4.053	4.148	N/A	4.309
2022		4.408	4.477	4.191	N/A	N/A	4.087	4.180	N/A	4.408
2023		4.506	4.599	4.223	N/A	N/A	4.119	4.206	N/A	4.506
2024		4.605	4.725	4.250	N/A	N/A	4.150	4.228	N/A	4.605
2025		4.704	4.854	4.274	N/A	N/A	4.178	4.246	N/A	4.704
2026		4.802	4.987	4.295	N/A	N/A	4.205	4.261	N/A	4.802
2027		4.901	5.124	4.313	N/A	N/A	4.230	4.273	N/A	4.901
2028		5.000	5.264	4.329	N/A	N/A	4.255	4.284	N/A	5.000
2029		5.098	5.408	4.342	N/A	N/A	4.278	4.292	N/A	5.098
2030		5.197	5.556	4.354	N/A	N/A	4.300	4.299	N/A	5.197

		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Coefficient	A	0	—	2	N/A	N/A	0.106	-0.730	N/A
	B	3	3	0.866	N/A	N/A	—	0.200	N/A
	C	—	—	—	—	3	3.1	—	N/A
	R	—	0.027	—	—	—	—	—	—
	K	—	—	4.430	N/A	—	—	4.330	N/A
Correlation coefficient		0.98055	0.97981	0.9642	N/A	N/A	0.93419	0.9664	N/A

Satulation value (K)

Formula No	Calculation	Validity	Applied	Reason
3	4.430	OK	4.430	
7	4.330	OK	4.330	

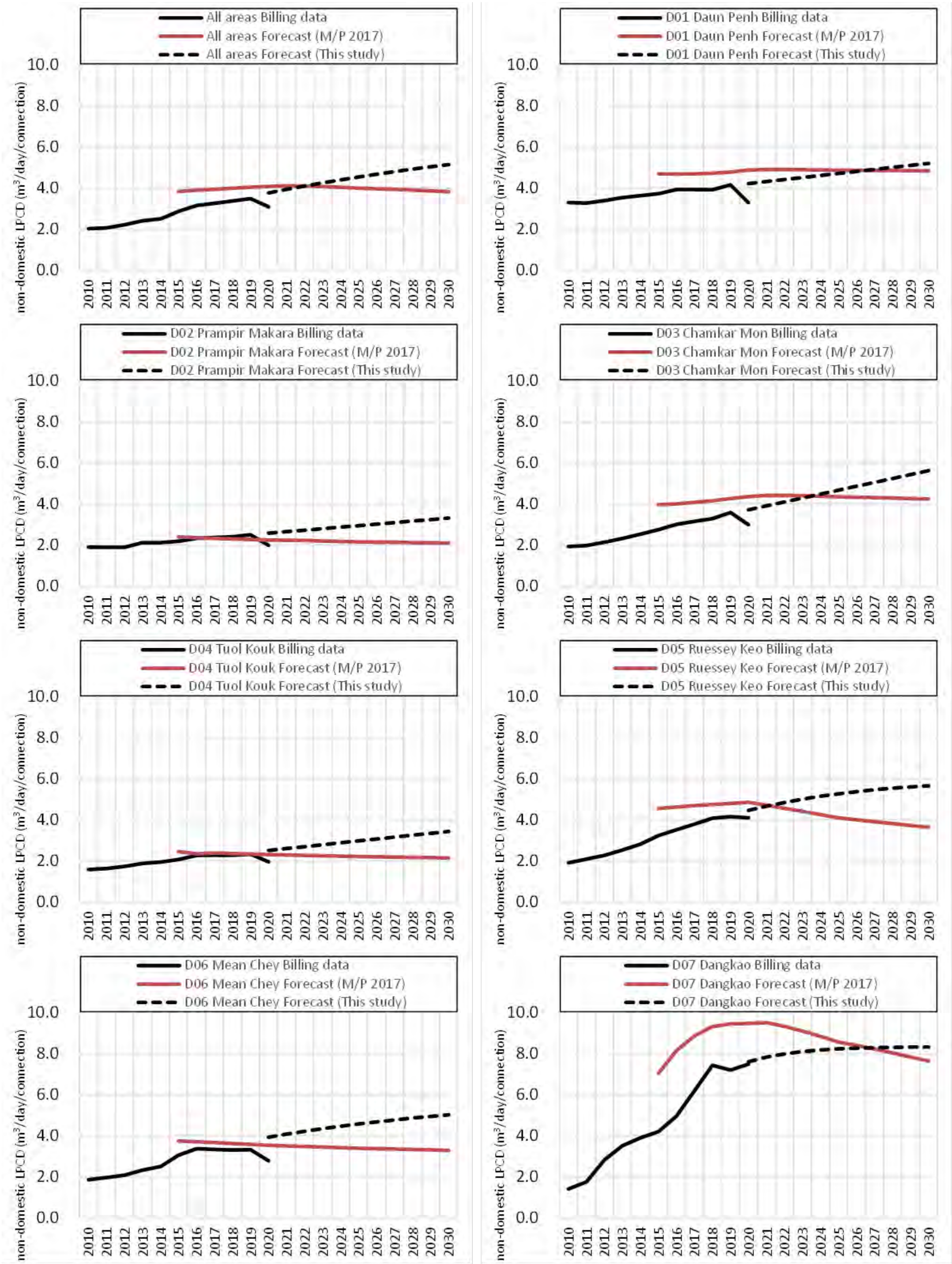


No	Item	Description	Applicable formula
a	Correlation coefficient: 0.70 or more	-	No.1,2,3,6,7
b	Trend (2010 - 2014, Period 1)	Increasing	No.1,2,3,6,7
c	Trend (2014 - 2019, Period 2)	Increasing	No.1,2,3,6,7
d	Expected changes in future	Increase trend is continued, since same kind of development seems to be predicted in this Khan.	No.1,2,3,6,7
e	Others	-	-

Applied formula	Reason	Remarks
No.1	The increase trend from 2010 to 2020 is linear. Same increase trend is assumed in future. So, No.1 is selected, since the formula No.1 has the characteristic of linear.	-

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

The non-domestic LPCD in the future was forecast based on the above method, and the results for all of the Khans are shown below.



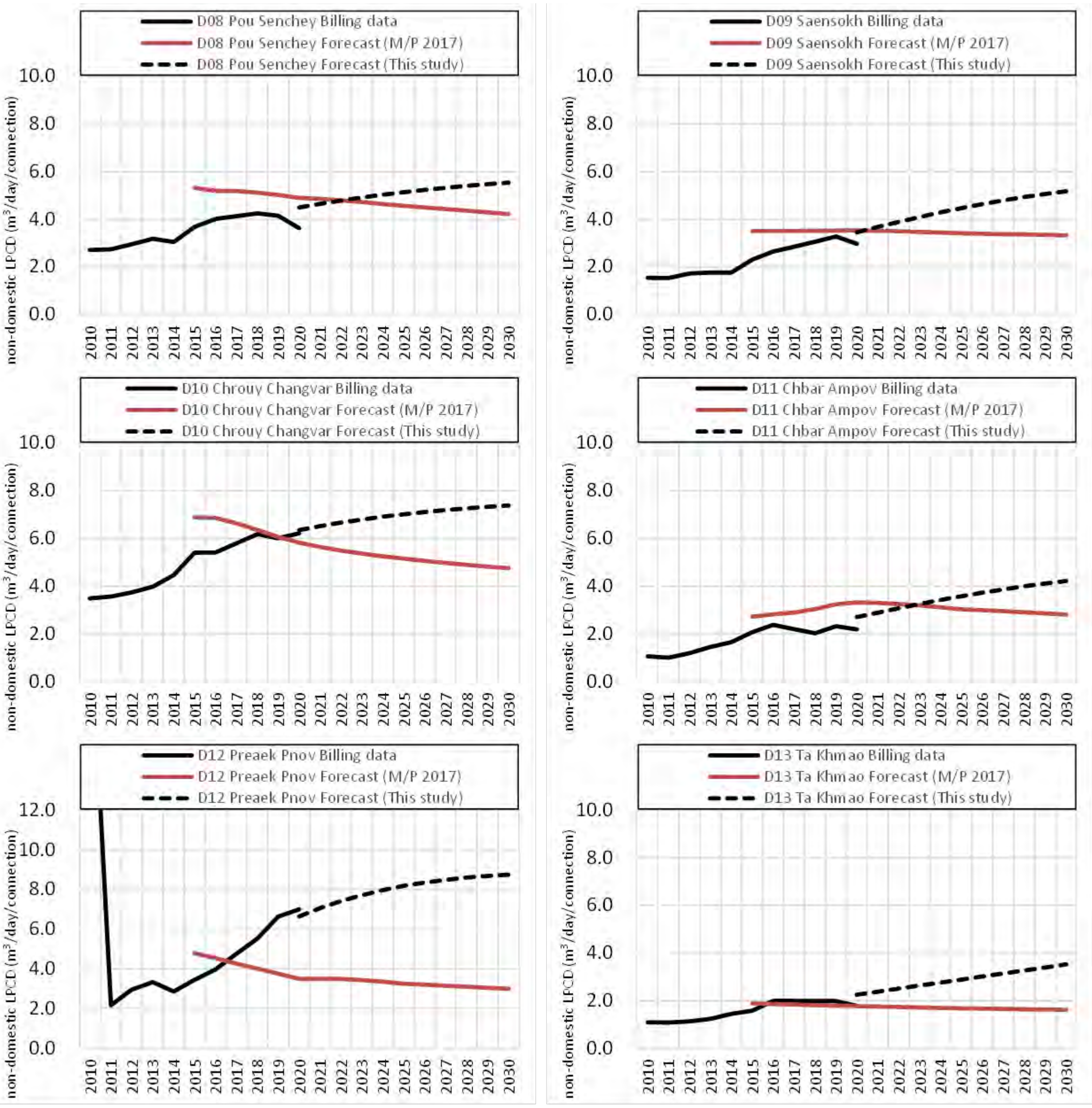


Figure 4.3.11 Results of the Forecasts on Non-Domestic LPCD for All the Khans
Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

4.3.4 Non-Revenue Water

Ratios of NRW or water losses applied in past water demand forecasts are shown in ***Table 4.3.9***. Actual NRW ratio of PPWSA's Performance Indicator (hereinafter referred to as "PI") data is shown in ***Table 4.3.10***. NRW ratios applied in the past water demand forecasts and the actual NRW ratio by PI data are shown in ***Figure 4.3.13*** for comparison.

Table 4.3.9 Applied NRW for the Water Demand Forecast in the Past M/P

STUDY	DESCRIPTION
M/P 2006	2005-2020: 15%
M/P 2013	Water losses 6.7-7.0%
M/P 2017	2015-2017: 8%, 2018-2019: 9%, 2020-2030: 10%

Source: M/P 2006, M/P 2013, M/P 2017

Table 4.3.10 NRW Ratio in PI Data

Unit: %

ITEM	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NRW ratio	6.2	6.2	5.9	5.8	6.7	6.6	7.7	8.1	8.4	9.0	9.9	10.0	10.0

Source: PPWSA

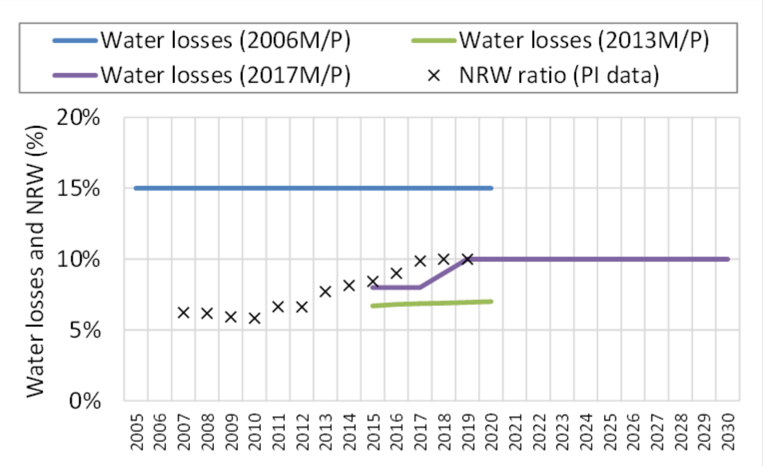


Figure 4.3.12 Comparison of Water Losses in the Past M/P and NRW Ratio in PI Data

Source: Prepared by JICA Data Collection Survey Team based on the M/P 2006, M/P 2013, M/P 2017, and PI data from PPWSA

Based on discussions with PPWSA, NRW ratio of 10% is applied until 2030 for the following reasons:

- PPWSA has a plan in place to keep the NRW ratio at 10%.
- PPWSA is carrying out the following efforts to keep/decrease the NRW ratio:
  - ➢ Replacement of old pipes
  - ➢ Replacement of water meters in every 11 years
  - ➢ Meter calibration
  - ➢ Leak detection
  - ➢ Leak repair
  - ➢ Public relation activities using Facebook etc.

4.3.5 Peak Factor

The peak factors applied in the past water demand forecasts and reasons for applying the peak factors are shown in ***Table 4.3.11***. The peak factors calculated from the production records from 2009 to 2020 are shown in ***Table 4.3.12*** and ***Figure 4.3.14***.

Table 4.3.11 Comparison of Applied Peak Factor for The Water Demand Forecast

STUDY	PEAK FACTOR	REMARKS
M/P 2006	1.30	-
M/P 2013	1.15	The peak factor in 2009 was 1.14 when the production capacity was sufficient.
M/P 2017	1.15	- The peak factor from 2002 to 2004 was large and decreased to 1.1 from 2005 to 2009. During those periods, production capacity was sufficient. - From 2010 to 2013, the production capacity was insufficient. - The production capacity was sufficient in 2014, since Niroth1 was completed. However, the peak factor was 1.096 - Considering the above, a peak factor of 1.15 was valid.

Source: M/P 2006, M/P 2013, M/P 2017

Table 4.3.12 Peak Factor

Year	Production (m^3/day)		Peak Factor
	Average	Max	
2009	252,116	280,630	1.11
2010	280,078	330,531	1.18
2011	299,388	320,438	1.07
2012	330,896	358,405	1.08
2013	371,289	397,261	1.07
2014	409,732	449,030	1.10
2015	446,984	483,488	1.08
2016	486,978	524,799	1.08
2017	531,610	578,632	1.09
2018	570,742	614,916	1.08
2019	607,278	662,537	1.09
2020	621,576	644,565	1.04

Source: PPWSA

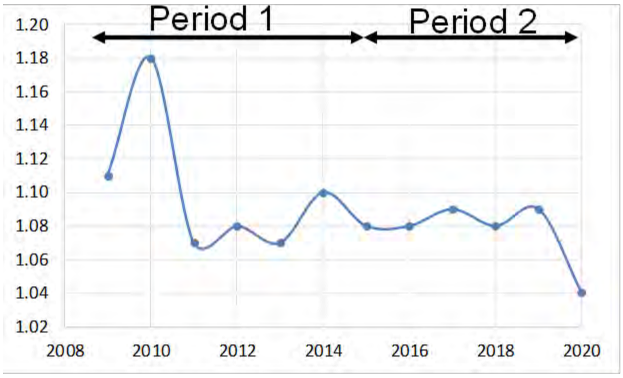


Figure 4.3.13 Peak Factor
Source: PPWSA

According to the peak factors applied in the past master plans, water demand forecasts and the actual peak factors shown in ***Table 4.3.12*** and ***Figure 4.3.14***, the peak factor to be applied for the water demand forecast is studied here.

When discussing peak factors, that fact that the current water production capacity in Phnom Penh is insufficient (as described in "**3.2.1(2) Water Production**") must be kept in mind. Therefore, the following should be considered:

- Total operation rate of all the WTPs in Phnom Penh is less than 100% during Period 1 (2009-2014) as shown in ***Figure 4.3.14***.
- Total operation rate of all the WTPs in Phnom Penh is more than 100% during Period 2 (after 2015) as shown in ***Figure 4.3.14***.

According to the above, the peak factor during Period 2 should not be considered. Therefore, only the peak factor during Period 1 should be considered. The peak factors during Period 1 are 1.10 to 1.18 and the peak factor in 2010 is especially high compared to other periods. The exceptional peak factor in 2010 should be excluded. It is thought that the 1.15 is appropriate for the peak factor considering the following situations:

- The peak factors are 1.07 to 1.11 during Period 1 except for 2010.
- The highest peak factor is 1.11 during Period 1 except for 2010. Some fluctuations may occur to the peak factor in the future
- The peak factor applied in the latest water demand forecast is 1.15.

Figure 4.3.14 shows the cases of peak factor range grouped by served population based on data from the water supply system in Japan for past 30 years. In case of served population over 1 million people, the peak factor ranges from 1.11 to 1.25. Therefore, it is thought that a peak factor of 1.15 is appropriate.

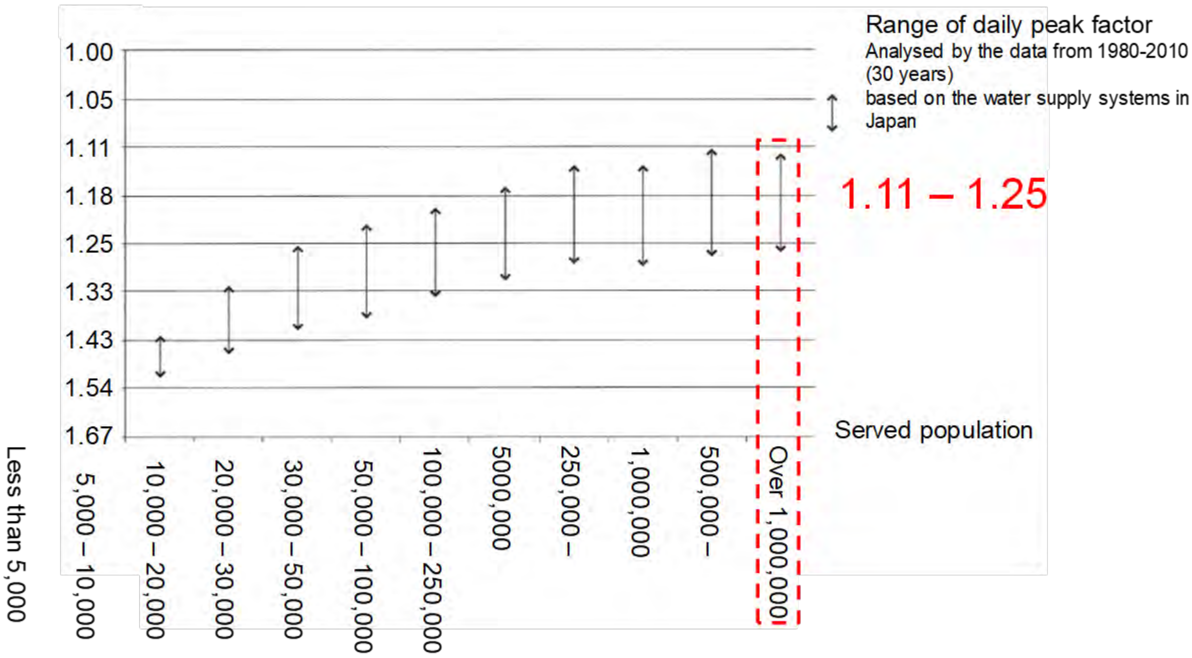


Figure 4.3.14 Peak Factor Analyzed by the Data in Waterworks in Japan During 1980-2010
Source: Japan Water Works Association (2012) Design Criteria for Waterworks Facilities

4.3.6 Water Demand Forecast without Consideration of Large-Scale Development Plan

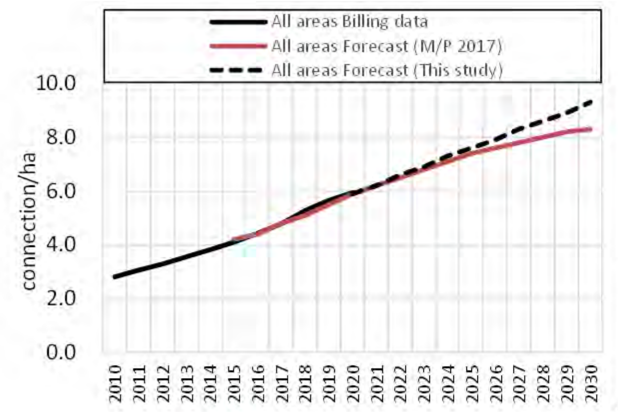
Table 4.3.13 shows the results of water demand forecast based on the above discussion. The results do not include the water demand of large-scale development plans. Therefore, the water demands of large-scale development plans are added to the results as shown in ***Table 4.3.13***. ***Figure 4.3.15*** illustrate figures of each item. The same figures of each Khan are shown in ***Appendix***.

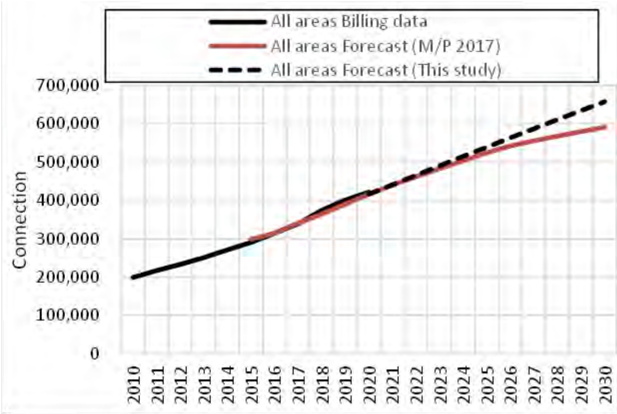
Table 4.3.13 Results of Water Demand Forecast (without Large-Scale Development Plans)

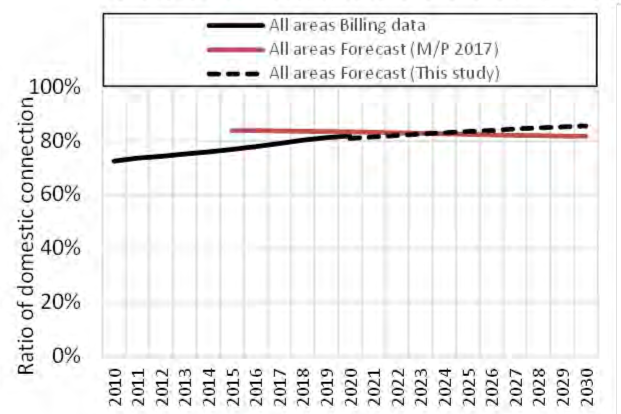
Item		Unit	Actual record										
			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Connection	domestic	Connection	144,469	159,573	173,313	188,695	205,545	223,041	244,636	267,711	300,899	325,734	345,002
	non-domestic	Connection	54,693	57,349	59,959	62,639	65,294	67,418	69,426	71,213	73,667	75,262	76,372
	total	Connection	199,162	216,922	233,272	251,334	270,839	290,459	314,062	338,924	374,566	400,996	421,374
Connection / ha		Connection / ha	2.81	3.06	3.29	3.55	3.82	4.1	4.43	4.78	5.28	5.66	5.94
Percent of domestic connection		%	72.5%	73.6%	74.3%	75.1%	75.9%	76.8%	77.9%	79.0%	80.3%	81.2%	81.9%
LPCD	domestic	m^3/day/connection	1.022	0.975	0.989	1.001	0.999	0.96	0.902	0.865	0.828	0.833	0.729
	non-domestic	m^3/day/connection	2.013	2.053	2.206	2.394	2.488	2.851	3.139	3.251	3.362	3.482	3.076
Consumption	domestic	m^3/day	147,673	155,526	171,371	188,801	205,431	214,215	220,633	234,886	249,139	271,234	251,567
	non-domestic	m^3/day	110,073	117,756	132,257	149,929	162,446	192,208	217,952	232,804	247,656	262,035	234,921
	total	m^3/day	257,746	273,282	303,628	338,730	367,877	406,423	438,585	467,690	496,795	533,269	486,488
NRW ratio		%	5.8%	6.7%	6.6%	7.7%	8.1%	8.4%	9.0%	9.9%	10.0%	10.0%	10.0%
Daily peak factor		-	1.18	1.07	1.08	1.07	1.1	1.08	1.08	1.09	1.08	1.09	1.04
Daily average water supply amount		m^3/day	278,604	297,665	329,096	369,140	406,969	444,307	483,784	527,392	565,861	602,393	549,549
Daily maximum water supply amount		m^3/day	320,395	342,315	378,460	424,511	468,014	510,953	556,352	606,501	650,740	692,752	631,981

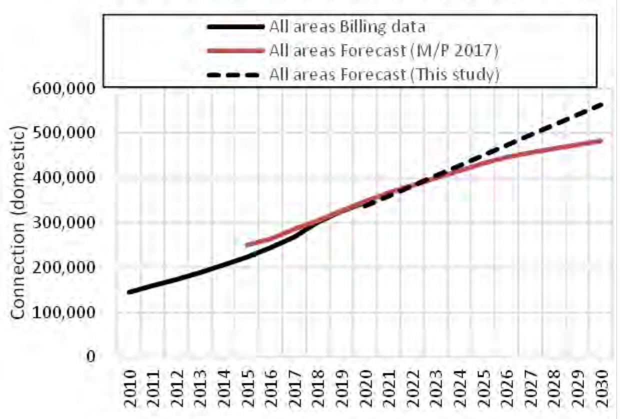
Item		Unit	Forecast									
			2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Connection	domestic	Connection	359,251	381,912	404,650	427,413	450,151	472,846	495,476	518,044	540,566	563,074
	non-domestic	Connection	81,610	83,689	85,619	87,389	88,996	90,438	91,718	92,844	93,826	94,682
	total	Connection	440,861	465,601	490,269	514,802	539,147	563,284	587,194	610,888	634,392	657,756
Connection / ha		Connection / ha	6.20	6.60	6.90	7.30	7.60	7.90	8.30	8.60	8.90	9.30
Percent of domestic connection		%	81.5%	82.0%	82.5%	83.0%	83.5%	83.9%	84.4%	84.8%	85.2%	85.6%
LPCD	domestic	m^3/day/connection	1.054	1.058	1.063	1.067	1.07	1.074	1.077	1.08	1.083	1.086
	non-domestic	m^3/day/connection	3.924	4.087	4.243	4.391	4.532	4.665	4.792	4.911	5.025	5.134
Consumption	domestic	m^3/day	378,557	404,209	430,024	455,935	481,881	507,833	533,762	559,671	585,578	611,524
	non-domestic	m^3/day	320,208	342,043	363,280	383,748	403,331	421,918	439,480	455,993	471,514	486,116
	total	m^3/day	698,765	746,252	793,304	839,683	885,212	929,751	973,242	1,015,664	1,057,092	1,097,640
NRW ratio		%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Daily peak factor		-	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Daily average water supply amount		m^3/day	776,406	829,169	881,448	932,982	983,568	1,033,058	1,081,380	1,128,515	1,174,549	1,219,600
Daily maximum water supply amount		m^3/day	892,866	953,545	1,013,665	1,072,931	1,131,104	1,188,018	1,243,590	1,297,793	1,350,732	1,402,540

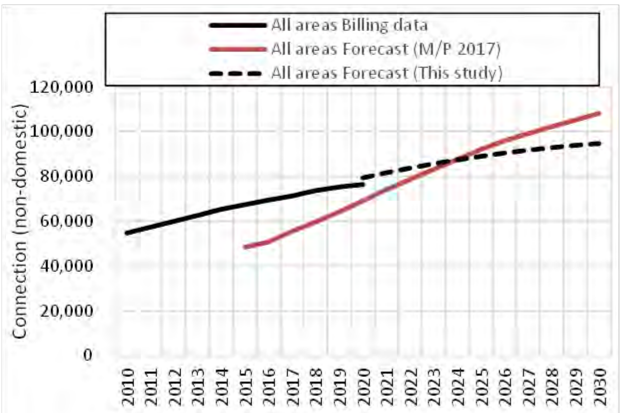
Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

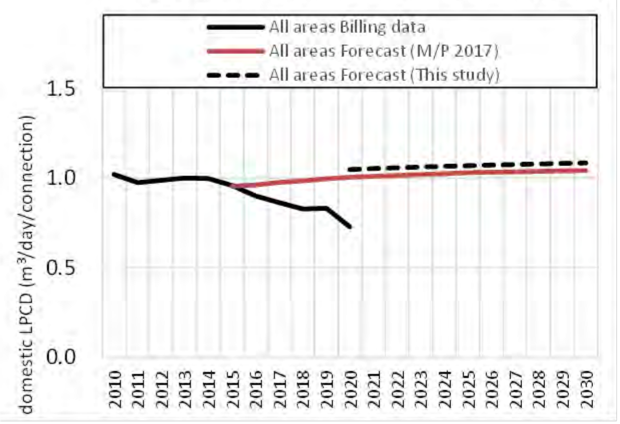

All areas Billing data
All areas Forecast (M/P 2017)
All areas Forecast (This study)
connection/ha

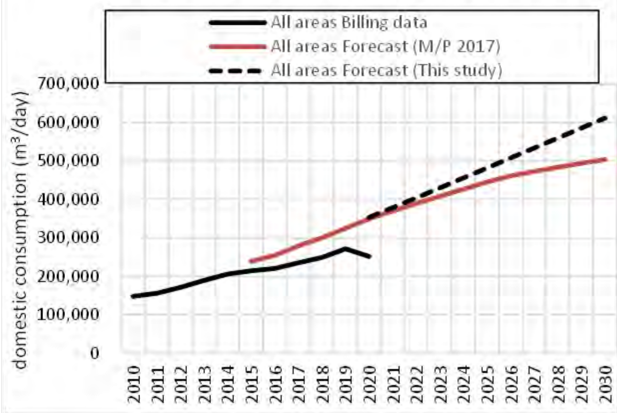

All areas Billing data
All areas Forecast (M/P 2017)
All areas Forecast (This study)
Connection


All areas Billing data
All areas Forecast (M/P 2017)
All areas Forecast (This study)
Ratio of domestic connection


All areas Billing data
All areas Forecast (M/P 2017)
All areas Forecast (This study)
Connection (domestic)


All areas Billing data
All areas Forecast (M/P 2017)
All areas Forecast (This study)
Connection (non-domestic)


All areas Billing data
All areas Forecast (M/P 2017)
All areas Forecast (This study)
domestic LPCD (m³/day/connection)


All areas Billing data
All areas Forecast (M/P 2017)
All areas Forecast (This study)
domestic consumption (m³/day)

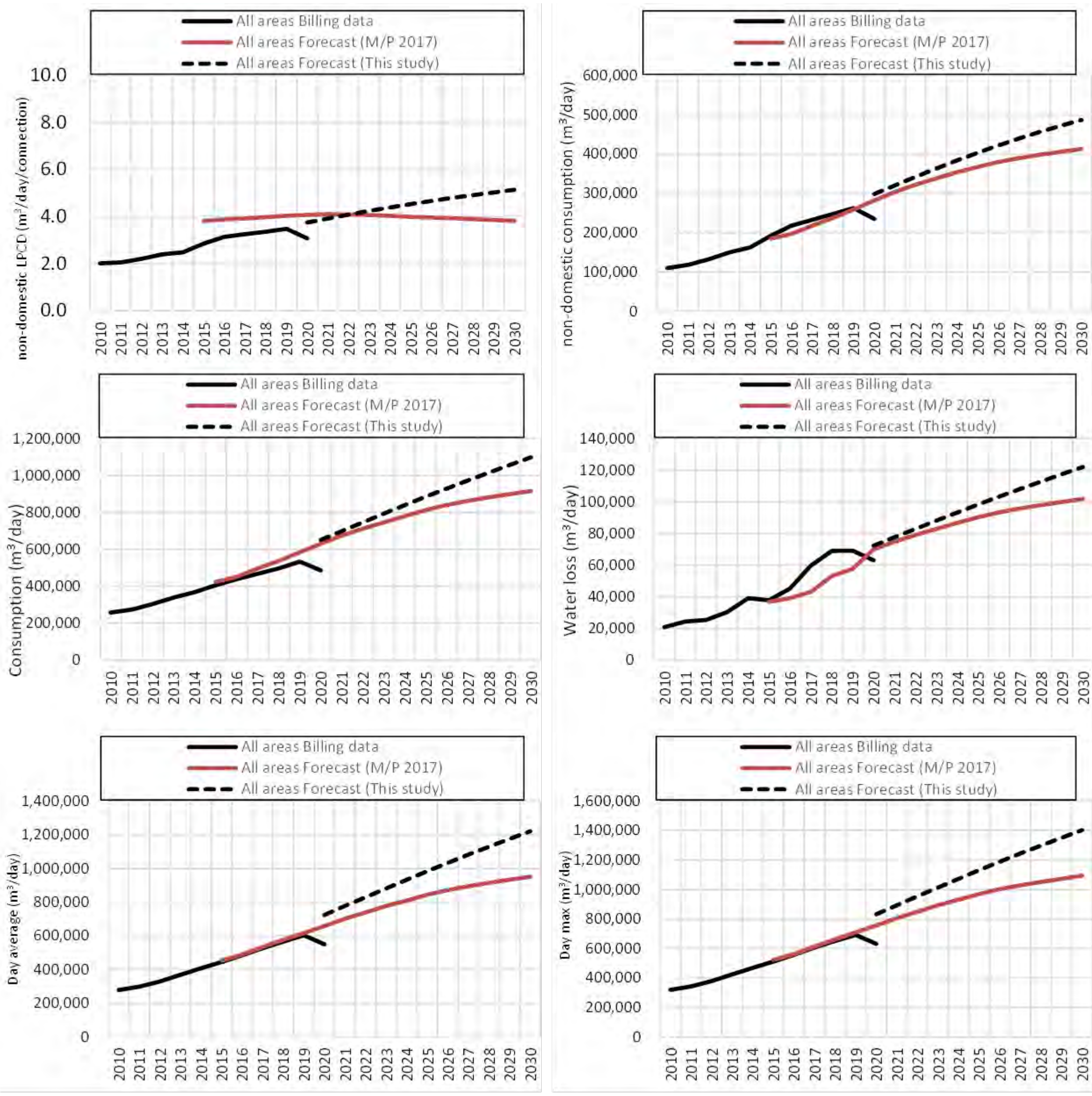


Figure 4.3.15 Water demand forecast for entire area without large-scale development plan

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

4.3.7 Consideration of Large-Scale Development Plans

(1) Grouping Large-Scale Development Plans

In order to carry out water demand forecast of large-scale development plans along the east and west sides of the Mekong River, they were grouped according to some salient characteristics to help account for certainties/uncertainties of each project. Three groups were prepared as shown in ***Table 4.3.14***.

Table 4.3.14 Grouping Large-Scale Development Plans

GROUP	DESCRIPTION
Group 1	Large-scale development plans − which have been already started − which will be started soon
Group 2	Large-scale development plans or areas currently supplied by private utilities − they are located in the west side of the Mekong River − There are uncertainties of whether: ➢ the project will be carried out or not ➢ they will continue to be supplied by private utilities continuously or be supplied by PPWSA in the future

Group 3	Areas currently supplied by private utilities − they are located in the east side of the Mekong River − There are uncertainties of whether: ➢ they will continue to be supplied by private utilities continuously or be supplied by PPWSA in the future

Source: Prepared by JICA Data Collection Survey Team based on the information provided by PPWSA

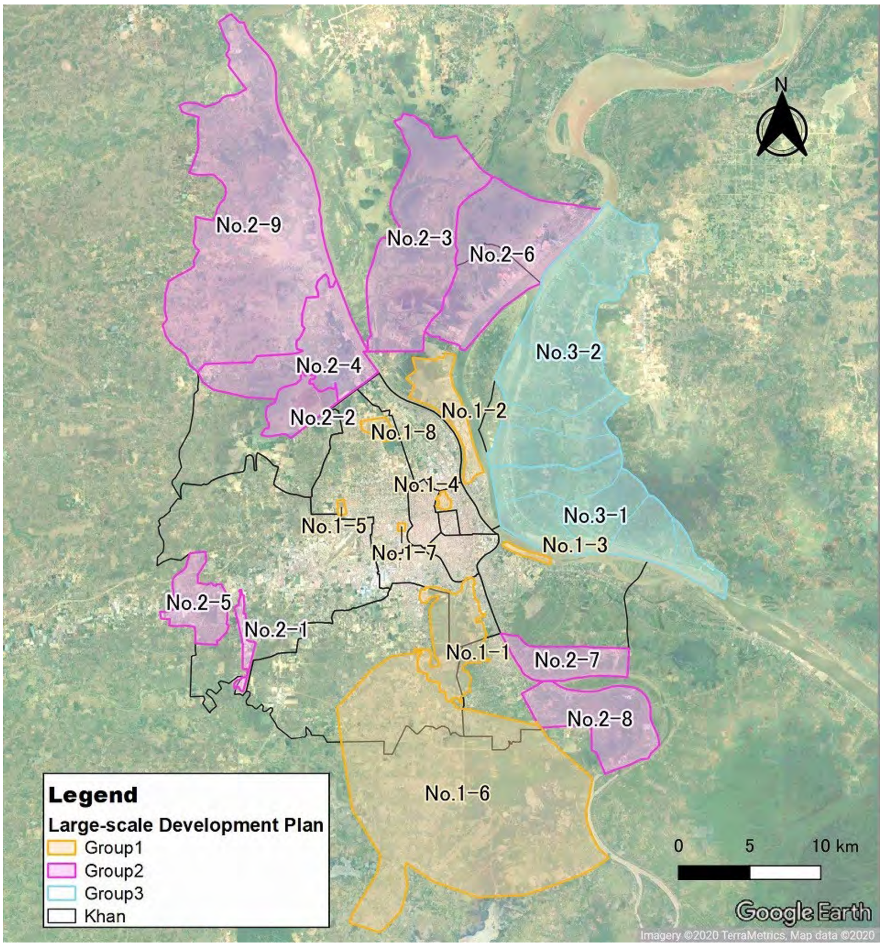


Figure 4.3.16 Location of Projects/Areas of the Group 1,2 and 3

Source: Prepared by JICA Data Collection Survey Team based on the information provided by PPWSA

(2) Water Demand of Group 1

1) Summary of Group 1

List of the projects of Group 1 is shown in ***Table 4.3.15*** and their locations are shown in ***Figure 4.3.17***.

Table 4.3.15 List of the Projects of Group 1

No	Name	Area	Khan	Schedule	Description
1-1	ING City	2,572 ha	Mean Chey Dangkao	2020-2040	4 stages, 5 years/stage, 2 stages are assumed to be completed by 2030
1-2	OCIC & Okide Villa	1,300 ha	Chroy Changvar	Around 2028 complete	Mainly Condominiums and residential areas.
1-3	Koh Norea Project	124 ha	Chbar Ampov	Around 2028 complete	Water demand is 30,000 m^3/day according to the project plan. Backfilling will be finished in the next 2 years, construction in 2028. Commercial, business, high-rise residential buildings.
1-4	Boeng Kak	80 ha	Daun Penh	Around 2026 complete	Business area, to be completed within 5 years
1-5	Okide Villa	50 ha	Pou Senchey	Around 2025 complete	Villa, few condominiums, business center, commercial area. Construction has already started.
1-6	New Airport City	2,600 ha	Outside	Stage 1 ends in 2023	Water demand of 1,000 m^3/day during construction.

No	Name	Area	Khan	Schedule	Description
				Stage 2 ends in 2030	
1-7	Booyoung Town	27 ha	Saensokh	Around 2026	40 apartments and 7 complexes, 17,760 units
1-8	Grand Phnom Penh International City	150 ha	Saensokh	Around 2030	Golf course and housing area

Source: Prepared by JICA Data Collection Survey Team based on the information provided by PPWSA

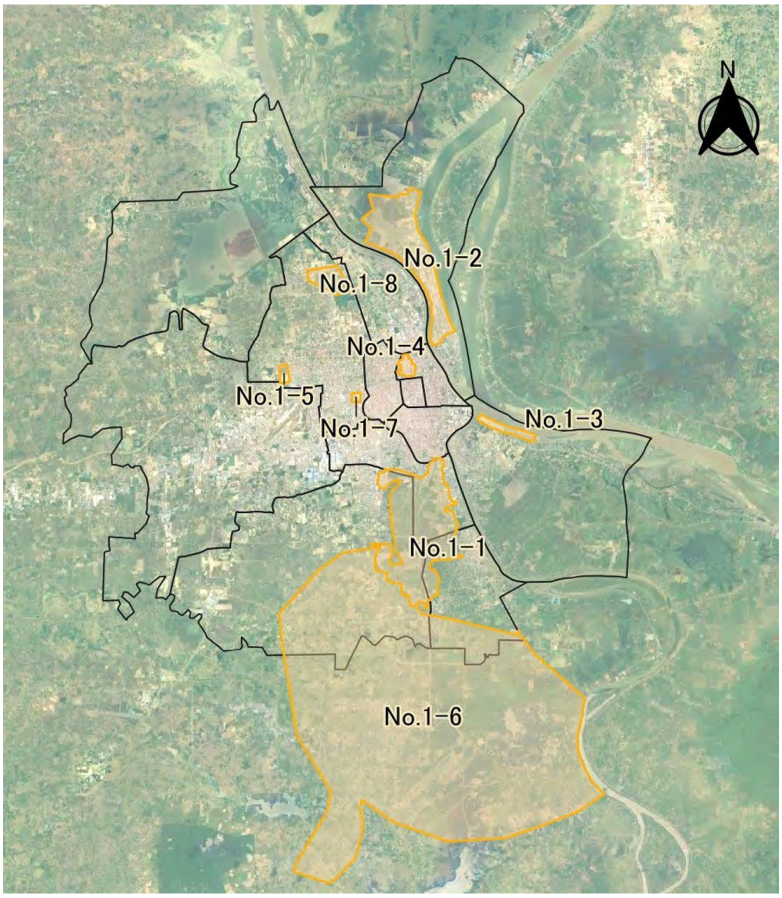


Figure 4.3.17 Location of Projects/Areas of the Group 1
Source: Prepared by JICA Data Collection Survey Team based on the information provided by PPWSA

2) ING City (No. 1-1)

The water demand is shown as 97,764 m^3/day at the completion of the entire project, as shown in ***Table 4.3.16***. This water demand can be regarded as consumption. Therefore, the day average demand and day maximum demand can be calculated from the consumption.

Table 4.3.16 Summary of the Water Demand Planned for ING City

Land Use	Water Demand (m^3/d)	Sewerage Flow (m^3/d)	Electric Demand (MW)
Residential	20,657	16,526	248
Mixed Use	15,093	12,074	507
CBD	9,117	7,294	357
Civic Institution	794	635	52
Hotel	699	559	33
Sports & Recreations	49,148	5,066	13
Educational Institutes	1,610	1,288	75
Social & Public Facilities	250	200	8
Industrial	397	317	49
Grand Total	**97,764**	**43,959**	**1,341**

Source: Development Project for ING City 2,572 Ha Cheung Aek Reservoir Area, 2014

3) OCIC & Okide Villa (No.1-2)

An area of approximately 1,300 hectares is under land preparation and construction. The type of the zoning is mainly residential. A high-density residential zone is expected after completion of the project. The number of connections per hectare in high density zones such as Khan Daun Penh, Chamkar Mon, and Tuol Kout, is in the range from 25 to 28 in 2020. With this in mind, the number of connections per hectare of OCIC & Okide Villa is set as 25 connections per hectare. Based on the connections per hectare, the water demand of OCIC & Okide villa is calculated as shown in ***Table 4.3.17***.

Table 4.3.17 Water Demand of OCIC & Okide Villa

Item		Unit	Condition	Remarks
(1) Area		ha	1,300	Target area
(2) Connection/ha		connection/ha	25	High dense area
(3) % of domestic connection		%	95	Residence area
(4) Connection	(4-1) Domestic	number	30,875	(4-3) X (3)
	(4-2) Non-domestic	number	1,625	(4-3) - (4-1)
	(4-3) Sub-total	number	32,500	(1) X (2)
(5) LPCD	(5-1) Domestic	m^3/day/connection	1.351	Chrouy Changvar in 2030
	(5-2) Non-domestic	m^3/day/connection	7.382	Chrouy Changvar in 2030
(6) Consumption	(6-1) Domestic	m^3/day	41,712	(4-1) X (5-1)
	(6-2) Non-domestic	m^3/day	11,996	(4-2) X (5-2)
	(6-3) Sub-total	m^3/day	53,708	(6-1) + (6-2)
(7) NRW		%	10	Chrouy Changvar in 2030
(8) Day Average Demand		m^3/day	59,676	(6-3) / (1-(7))
(9) Day Maximum Demand		m^3/day	68,627	(8) X 1.15

Source: JICA Data Collection Survey Team

4) Koh Norea Project (No.1-3)

The master plan of the project reports water demand of the project as 30,000 m^3/day. This water demand is regarded as day maximum demand, since the 30,000 m^3/day is quite high considering the project area.

5) Boeng Kak (No.1-4)

An area of approximately 80 hectares is currently under development. The type of the zoning will mainly be business. In order to estimate the water demand for the area, other similar areas types were studied, as shown in ***Table 4.3.18*** and ***Figure 4.3.18***. The condition of the "business zone" shown in ***Table 4.3.18*** seems to be appropriate for the estimation of water demand in this project area. Therefore, the water demand shown in ***Table 4.3.19*** is applied.

Table 4.3.18 Number of Connections and Consumption

Name	Connection 2020	Area (ha)	Connection /ha	Consumption[1)]	
				m^3/day	m^3/day/ha
Business Zone	343	78.3	4.4	5,603	71.6
Center 1	85	6.3	13.5	171	27.1
Center 2	3	6.6	0.5	145	22
North	7	26.7	0.3	4	0.1
South	316	71	4.5	733	10.3
west side	4,029	205.2	19.6	9,282	45.2
Total	4,783	394	12.1	15,939	40.5

1) Consumption in Sep. and Oct. in 2019

Source: Prepared by JICA Data Collection Survey Team based on the billing data provided by PPWSA

Figure 4.3.18 Case Study for Consumption
Source: Google map

Table 4.3.19 Water Demand of Boeng Kak

Item		Unit	Condition	Remarks
(1) Area		ha	80	Target area
(2) Connection/ha		connection/ha	5	Consideration of business zone
(3) % of domestic connection		%	20	Consideration of business zone
(4) Connection	(4-1) Domestic	number	80	(4-3) X (3)
	(4-2) Non-domestic	number	320	(4-3) - (4-1)
	(4-3) Sub-total	number	400	(1) X (2)
(5) LPCD	(5-1) Domestic	m^3/day/connection	1.015	Daun Penh in 2030
	(5-2) Non-domestic	m^3/day/connection	18	Consideration of business zone
(6) Consumption	(6-1) Domestic	m^3/day	81	(4-1) X (5-1)
	(6-2) Non-domestic	m^3/day	5,760	(4-2) X (5-2)
	(6-3) Sub-total	m^3/day	5,841	(6-1) + (6-2)
(7) NRW		%	10	Daun Penh in 2030
(8) Day Average Demand		m^3/day	6,490	(6-3) / (1-(7))
(9) Day Maximum Demand		m^3/day	7,464	(8) X 1.15
Ref. consumption/ha		m^3/day/ha	73.0	(6-3) / (1)

Source: JICA Data Collection Survey Team

6) Okide Villa (No.1-5)

An area of approximately 50 hectares is under land preparation. The type of the zoning will mainly be residential. High density is expected after completion of the project. The number of connections per hectare in high density zones such as Khan Daun Penh, Chamkar Mon and Tuol Kout, is in the range from 25 to 28 in 2020. With this in mind, the number of connections per hectare in Okide Villa is set as 25 connections per hectare. Based on the connections per hectare, the water demand of Okide villa is calculated as shown in ***Table 4.3.20***.

Table 4.3.20 Water Demand of Okide Villa

Item		Unit	Condition	Remarks
(1) Area		ha	50	Target area
(2) Connection/ha		connection/ha	25	Consideration of high density zones
(3) % of domestic connection		%	90	Residense zone
(4) Connection	(4-1) Domestic	number	1,125	(4-3) X (3)
	(4-2) Non-domestic	number	125	(4-3) - (4-1)
	(4-3) Sub-total	number	1,250	(1) X (2)
(5) LPCD	(5-1) Domestic	m^3/day/connection	1.196	Pou Senchey in 2030
	(5-2) Non-domestic	m^3/day/connection	5.529	Pou Senchey in 2030
(6) Consumption	(6-1) Domestic	m^3/day	1,346	(4-1) X (5-1)
	(6-2) Non-domestic	m^3/day	691	(4-2) X (5-2)
	(6-3) Sub-total	m^3/day	2,037	(6-1) + (6-2)
(7) NRW		%	10	Pou Senchey in 2030
(8) Day Average Demand		m^3/day	2,263	(6-3) / (1-(7))
(9) Day Maximum Demand		m^3/day	2,602	(8) X 1.15

Source: JICA Data Collection Survey Team

7) New Airport City (No.1-6)

The water demand of the New Airport City is shown in ***Table 4.3.21*** based on the information provided by PPWSA.

Table 4.3.21 Water demand by New Airport City

Year	Water demand (m^3/day)
2022	5,500
2023	7,700
2024	9,900
2025	12,100
2026	14,300
2027	16,500
2028	18,700
2029	20,900
2030	23,100

Source: PPWSA

8) Booyoung Town (No.1-7)

The area with approximately. 27 hectares is under construction. The area consists of residential and commercial zones although it is mostly residential. Many high-rise apartments are planned and under construction in the area. A total of 1,474 rooms are planned at completion. Therefore, very high density is expected after completion of the project.

Considering the 1,474 rooms, the connections per hectare is expected to be around 250. Based on the this number, the water demand by Booyoung Town is calculated as shown in ***Table 4.3.22***.

Table 4.3.22 Water Demand of Booyoung Town

Item		Unit	Condition	Remarks
(1) Area		ha	22	Target area
(2) Connection/ha		connection/ha	250	Consideration of high density zones
(3) % of domestic connection		%	85	Residense and commercial zone
(4) Connection	(4-1) Domestic	number	4,675	(4-3) X (3)
	(4-2) Non-domestic	number	825	(4-3) - (4-1)
	(4-3) Sub-total	number	5,500	(1) X (2)
(5) LPCD	(5-1) Domestic	m^3/day/connection	1.042	Saensokh in 2030
	(5-2) Non-domestic	m^3/day/connection	5.173	Saensokh in 2030
(6) Consumption	(6-1) Domestic	m^3/day	4,871	(4-1) X (5-1)
	(6-2) Non-domestic	m^3/day	4,268	(4-2) X (5-2)
	(6-3) Sub-total	m^3/day	9,139	(6-1) + (6-2)
(7) NRW		%	10	Pou Senchey in 2030
(8) Day Average Demand		m^3/day	10,154	(6-3) / (1-(7))
(9) Day Maximum Demand		m^3/day	11,677	(8) X 1.15

Source: JICA Data Collection Survey Team

9) Grand Phnom Penh International City (No. 1-8)

An area of approximately 150 hectares is under construction. The area includes a golf course and residential area. Therefore, the population density will be lower than other areas. Considering the situation, the water demand is calculates as shown in ***Table 4.3.23***.

Table 4.3.23 Water Demand of Grand Phnom Penh International City

Item		Unit	Condition	Remarks
(1) Area		ha	150	Target area
(2) Connection/ha		connection/ha	15	Consideration of low density
(3) % of domestic connection		%	80	Golf course and resident
(4) Connection	(4-1) Domestic	number	1,800	(4-3) X (3)
	(4-2) Non-domestic	number	450	(4-3) - (4-1)
	(4-3) Sub-total	number	2,250	(1) X (2)
(5) LPCD	(5-1) Domestic	m^3/day/connection	1.042	Saensokh in 2030
	(5-2) Non-domestic	m^3/day/connection	5.173	Saensokh in 2030
(6) Consumption	(6-1) Domestic	m^3/day	1,876	(4-1) X (5-1)
	(6-2) Non-domestic	m^3/day	2,328	(4-2) X (5-2)
	(6-3) Sub-total	m^3/day	4,204	(6-1) + (6-2)
(7) NRW		%	10	Saensokh in 2030
(8) Day Average Demand		m^3/day	4,671	(6-3) / (1-(7))
(9) Day Maximum Demand		m^3/day	5,372	(8) X 1.15

Source: JICA Data Collection Survey Team

10) Summary of Water Demand of Group 1

Summary of the water demand of the large-scale development plans is shown in ***Table 4.3.24***. The day average and day maximum demands are calculated by the following conditions:

- NRW ratio: 10%
- Peak factor: 1.15

Table 4.3.24 Summary of Water Demand of Group 1

No	1. Development project	Area (ha)	Consumption (m^3/day)	Day average (m^3/day)	Day max (m^3/day)
1-1	ING city	2,572	97,765	108,628	124,922
1-2	OCIC & Okide Villa	1,300	53,708	59,676	68,627
1-3	Kos Norea Project	124	23,478	26,087	30,000
1-4	Boeng Kak	80	5,841	6,490	7,464
1-5	Okide Villa	50	2,037	2,263	2,603
1-6	New Phnom Penh Airport	2,600	18,078	20,087	23,100
1-7	Booyoung Town	27	9,139	10,154	11,678
1-8	Grand Phnom Penh international City	150	4,204	4,671	5,372
Total		6,903	214,250	238,056	273,766

Source: JICA Data Collection Survey Team

11) Staged Water Demands of Group 1

The water demand of Group 1 until 2030 is calculated by the following methods. The detailed conditions of the calculation are shown in ***Table 4.3.25***, and the results are shown in ***Table 4.3.26***.

- After starting the project, the water demand of the construction site will be estimated based on the water bill of each construction site if such billing data is available. If it is not available, water consumption during construction will be estimated. During the period, water will be used only for construction purposes and there will be no residential or commercial users.
- After the construction period, water consumption will slowly increase as people gradually move into the project areas.
- Some time will pass from the completion of construction until the area reaches full resident capacity. Therefore, some time periods are set until full water demand is reached.

Table 4.3.25 Conditions to Calculate the Staged Water Demand of Large-scale Development Plans

No	Project	Area	Day max	Completion year	Construction period 1)	Project period 2)	Until full demand 3)	Water use during construction	Water demand progress of each project (%) 5)										
		(ha)	(m^3/day)		Year	Year	Year	m^3/day	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040
1-1	ING city	2,572	124,922	2040	3	20	0	1,038	-	-	5%	8%	10%	15%	20%	25%	35%	50%	100%
1-2	OCIC+Okide Villa	1,300	68,627	2028	3	10	2	2,313	-	5%	10%	15%	20%	25%	30%	50%	75%	100%	100%
1-3	Kos Norea Project	124	30,000	2028	4	10	2	500	-	-	-	-	5%	10%	15%	30%	45%	100%	100%
1-4	Boeng Kak	80	7,464	2026	2	6	2	1,109	-	-	10%	20%	30%	50%	70%	100%	100%	100%	100%
1-5	Okide Villa	50	2,603	2025	0	5	1	87	10%	20%	30%	50%	70%	100%	100%	100%	100%	100%	100%
1-6	New Phnom Penh Airport	2,600	23,100	2030	1	10	9	1,000	-	24%	33%	43%	52%	62%	71%	81%	90%	100%	100%
1-7	Booyoung Town	27	11,678	2026	0	6	2	604	15%	20%	30%	40%	50%	65%	80%	100%	100%	100%	100%
1-8	Grand Phnom Penh international City	150	5,372	2028	0	10	2	2,238	50%	55%	60%	65%	70%	75%	80%	85%	90%	100%	100%
	Total	6,903	273,766	-	-	-	-	8,889	3.9%	6.4%	10.8%	15.0%	19.5%	26.0%	32.2%	43.7%	57.0%	77.2%	100.0%

1) Years to use water only by construction from year 2021
2) Years until compleretion of project from year 2021
3) Years until reaching to full demand after completion of each project
4) Water use amount during construction calculated from billed amount
5) Hyphen in the table means construction period without use by residence

Source: JICA Data Collection Survey Team

Table 4.3.26 Staged Water Demand Of Group 1

No	Project	Area	Day max	Completion year	Construction period 1)	Project period 2)	Until full demand 3)	Water use 4) during construction	Water demand (m3/day)										
		(ha)	(m^3/day)		Year	Year	Year	m^3/day	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040
1-1	ING city	2,572	124,922	2040	3	20	0	1038	1,038	1,038	6,246	9,369	12,492	18,738	24,984	31,231	43,723	62,461	124,922
1-2	OCIC+Okide Villa	1,300	68,627	2028	1	10	2	2313	2,313	3,431	6,863	10,294	13,725	17,157	20,588	34,314	51,470	68,627	68,627
1-3	Kos Norea Project	124	30,000	2028	4	10	2	500	500	500	500	500	1,500	3,000	4,500	9,000	13,500	30,000	30,000
1-4	Boeng Kak	80	7,464	2026	2	6	2	1,109	1,109	1,109	746	1,493	2,239	3,732	5,225	7,464	7,464	7,464	7,464
1-5	Okide Villa	50	2,603	2025	0	5	1	87	260	521	781	1,302	1,822	2,603	2,603	2,603	2,603	2,603	2,603
1-6	New Phnom Penh Airport	2,600	23,100	2030	1	10	9	1000	1,000	5,500	7,700	9,900	12,100	14,300	16,500	18,700	20,900	23,100	23,100
1-7	Booyoung Town	27	11,678	2026	0	6	2	604	1,752	2,336	3,503	4,671	5,839	7,591	9,342	11,678	11,678	11,678	11,678
1-8	Grand Phnom Penh international City	150	5,372	2028	0	10	2	2238	2,686	2,955	3,223	3,492	3,760	4,029	4,298	4,566	4,835	5,372	5,372
	Total	6,903	273,766	-	-	-	-	8,889	10,658	17,389	29,563	41,021	53,478	71,150	88,040	119,555	156,173	211,305	273,766

1) Years to use water only by construction from year 2021
2) Years until compleretion of project from year 2021
3) Years until reaching to full demand after completion of each project
4) Water use amount during construction calculated from billed amount

Source: JICA Data Collection Survey Team

(3) Water Demand of Group 2

1) Summary of Group 2

List of the projects of Group 2 is shown in ***Table 4.3.27*** and their locations are shown in ***Figure 4.3.19***.

Table 4.3.27 List of the Projects/Areas of Group 2

NO	NAME	KHAN	CURRENT WATER SUPPLY
2-1	Special Economic Zone (SEZ)	Pou Senchey	5,300 m^3/day (SEZ's own WTP)
2-2	Tamok Lake	Preaek Pnov	None
2-3	Arey Khsat & Leva Aem commune	Kandal Province	4,800 m^3/day
2-4	Prek Pnov	Preaek Pnov	14,400 m^3/day
2-5	Bek Chan	Kanda Province	10,800 m^3/day
2-6	North of Chroy Changvar	Chroy Changvar	7,200 m^3/day
2-7	South of Chbar Ampov	Chbar Ampov	2,400 m^3/day
2-8	East of Ta Khmau	Ta Khmau	500 m^3/day
2-9	Private utility area	Ponhea Lueu	6,172 m^3/day

Source: Prepared by JICA Data Collection Survey Team based on the information provided by PPWSA

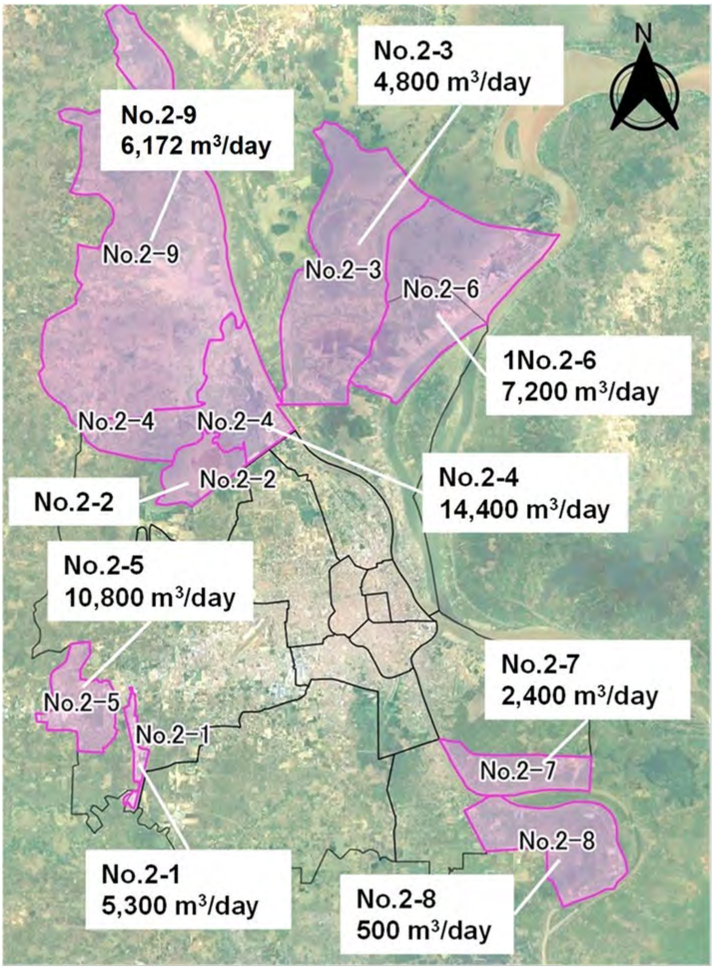


Figure 4.3.19 Location of Projects/Areas of the Group 2 with Current Private WTPs Capacity
Source: Google map

2) Water Demand of Group 2

There is little data available regarding Group 2 projects to sufficiently calculate future water demands. In order to estimate the water demand, the ratio of water demand between 2019 and 2030 is applied as shown below.

Water demand ratio: (2)/(1) = 1,402,540/692,752 ≒ 2.0

The above ratio is derived from the results of water demand forecast (without large-scale development plans) as shown in ***Table 4.3.13***.

The calculated water demand ratio is multiplied with the current water demand or current water supply capacity, and the results are as shown in ***Table 4.3.28***.

Table 4.3.28 Water Demand of Group 2

No	Name	Khan	Current Capacity	Water Demand in 2030
2-1	Special Economic Zone (SEZ)	Pou Senchey	5,300 m^3/day (SEZ's own WTP)	10,600 m^3/day (SEZ; 5,300, PPWSA; 5,300)
2-2	Tamok Lake	Preaek Pnov	None	8,108 m^3/day
2-3	Arey Khsat & Leva Aem Commune	Kandal Province	4,800 m^3/day	9,600 m^3/day
2-4	Prek Pnov	Preaek Pnov	14,400 m^3/day	28,800 m^3/day
2-5	Bek Chan	Kanda Province	10,800 m^3/day	21,600 m^3/day
2-6	North of Chroy Changvar	Chroy Changvar	7,200 m^3/day	14,400 m^3/day
2-7	South of Chbar Ampov	Chbar Ampov	2,400 m^3/day	4,800 m^3/day
2-8	East of Ta Khmau	Ta Khmau	500 m^3/day	1,000 m^3/day
2-9	Private utility area	Ponhea Lueu	6,172 m^3/day	8,451 m^3/day*1)
Total			45,400 m^3/day	107,359 m^3/day (PPWSA; 102,059, SEZ; 5,300)

1) provided by PPWSA
Source: JICA Data Collection Survey Team

(4) Water Demand of Group 3

1) Summary of Group 3

List of the projects of Group 3 is shown in **Table *4.3.29*** and their locations are as shown in ***Figure 4.3.20***.

Table 4.3.29 List of the Projects/Areas of Group 3

NO	NAME	KHAN	CURRENT CAPACITY
3-1	Arey Khsat & Leva Aem commune (private)	Pou Senchey	2,400 m^3/day
3-2	Preaek Luong, Preaek Takov, Svay Chrum, Preaek Ta Mak, Preaek Ampil, Puk Russei	Preaek Pnov	11,880 m^3/day

Source: Prepared by JICA Data Collection Survey Team based on the information provided by PPWSA

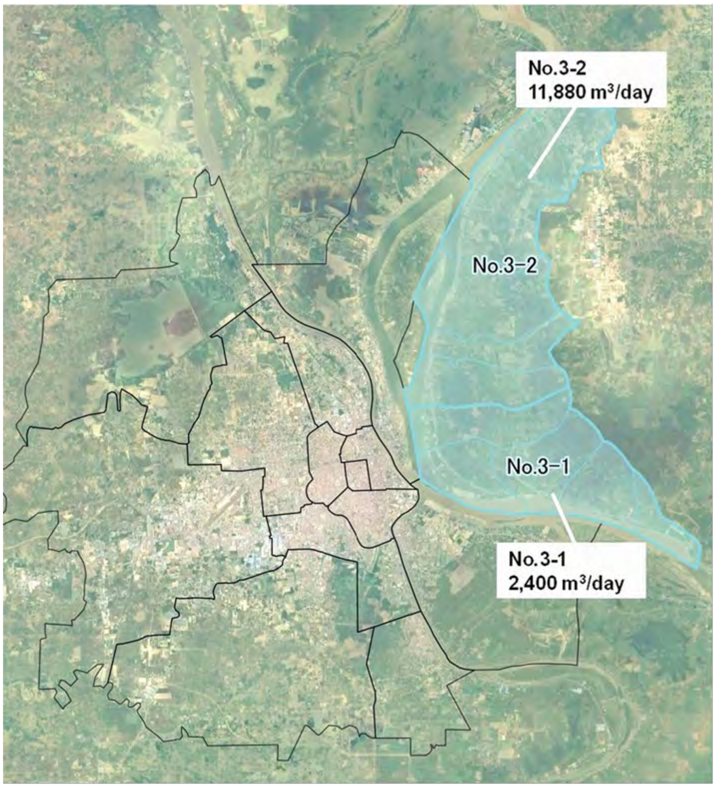


Figure 4.3.20 Location of Projects/Areas of Group 3 with Current Private WTPs Capacity
Source: Google map

2) Water Demand of Group 3

The same method as Group 2 is applied to calculate the water demand by Group 3 and the results are as shown in ***Table 4.3.30***. Water demand as shown in "OCIC & Okide Villa (No.1-2)" is expected in No. 3-1, since the bridge across the Mekong River is planned. Therefore, water demand shown in ***Table 4.3.31*** is applied.

Table 4.3.30 Water Demand of Group 3

No	Name	Khan	Current Capacity	Water Demand in 2030
3-1	Arey Khsat & Leva Aem commune (private)	Pou Senchey	2,400 m^3/day	73,907 m^3/day
3-2	Preaek Luong, Preaek Takov, Svay Chrum, Preaek Ta Mak, Preaek Ampil, Puk Russei	Preaek Pnov	11,880 m^3/day	23,760 m^3/day
Total			14,280 m^3/day	97,667 m^3/day

Source: JICA Data Collection Survey Team

Table 4.3.31 Water Demand of No.3-1

Item		Unit	Condition	Remarks
(1) Area		ha	1,400	
(2) Connection/ha		connection/ha	25	
(3) % of domestic connection		%	95	Residential area
(4) Connection	(4-1) Domestic	number	33,250	
	(4-2) Non-domestic	number	1,750	
	(4-3) Sub-total	number	35,000	
(5) LPCD	(5-1) Domestic	m^3/day/connection	1.351	Average in 2030
	(5-2) Non-domestic	m^3/day/connection	7.382	Average in 2030
(6) Consumption	(6-1) Domestic	m^3/day	44,921	
	(6-2) Non-domestic	m^3/day	12,919	
	(6-3) Sub-total	m^3/day	57,840	
(7) NRW		%	10	Average in 2030
(8) Day Average Demand		m^3/day	64,267	(6-3) / (1-(7))
(9) Day Maximum Demand		m^3/day	73,907	(8) X 1.15

Source: JICA Data Collection Survey Team

(5) Summary of Water Demand of Large-Scale Development Plans

The summary of water demand including large-scale development plans is shown in ***Table 4.3.32***.

Table 4.3.32 Summary of Water Demand of Large-Scale Development Plans

Unit: m^3/day

Item		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
ADD	1. M/P 2017	700,587	738,288	776,568	809,187	843,056	871,408	893,869	914,618	932,470	950,478
	2. This study (Basic)	776,406	829,169	881,448	932,982	983,568	1,033,058	1,081,380	1,128,515	1,174,549	1,219,600
	3. This study (Group 1)	9,547	11,684	20,075	35,734	46,503	61,867	76,554	103,959	135,798	183,739
	4. This study (Group 2)	0	0	0	0	62,558	67,564	72,570	77,570	82,576	88,748
	5. This study (Group 3)	0	0	0	0	63,696	67,942	72,188	76,436	80,681	84,928
	6. This study (Total)	786,000	841,000	902,000	969,000	1,157,000	1,231,000	1,303,000	1,387,000	1,474,000	1,578,000
MDD	1. M/P 2017	805,676	849,032	893,053	930,565	969,514	1,002,119	1,027,949	1,051,810	1,072,340	1,093,050
	2. This study (Basic)	892,866	953,545	1,013,665	1,072,931	1,131,104	1,188,018	1,243,590	1,297,793	1,350,732	1,402,540
	3. This study (Group 1)	10,978	13,437	23,086	41,095	53,481	71,146	88,036	119,554	156,168	211,305
	4. This study (Group 2)	0	0	0	0	71,937	77,691	83,450	89,200	94,958	102,059
	5. This study (Group 3)	0	0	0	0	73,250	78,133	83,016	87,901	92,783	97,667
	6. This study (Total)	904,000	967,000	1,037,000	1,115,000	1,330,000	1,415,000	1,499,000	1,595,000	1,695,000	1,814,000

Source: JICA Data Collection Survey Team

4.3.8 Considering the Impacts OF COVID-19

The billing data shown in ***Figure 4.3.21*** shows significant decrease in water consumption. Based on current conditions, it is assumed that water use in 2021 will not increase dramatically due to the continued suspension of some investments and foreign tourists, etc. Water demand forecasts need to consider such impacts of the COVID-19 pandemic.

It is assumed that the water demand of Group 1,2, and 3 will not be affected by COVID-19 since their water demands will not be relevant for several years. This study considers the impact of COVID-19 on water demand forecast, without Group 1,2, and 3 as shown in ***Table 4.3.33***.

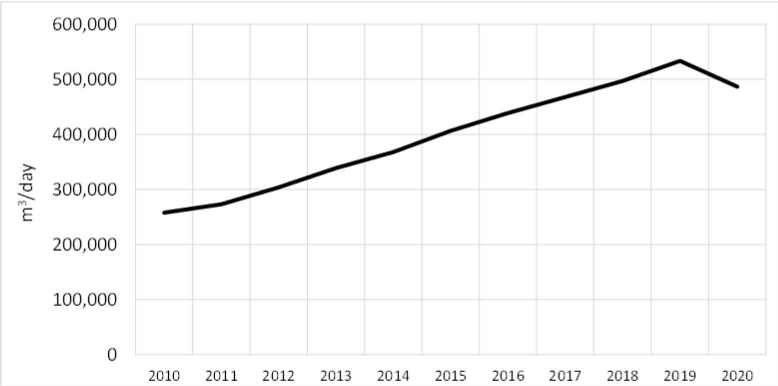


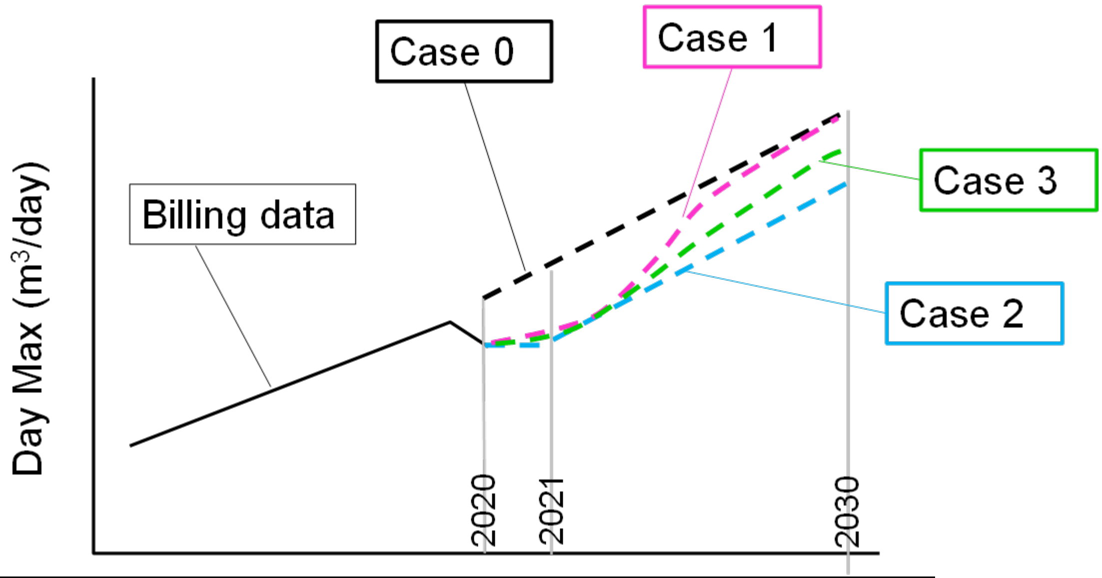
Figure 4.3.21 Significant decrease of water consumption
Source: billing data by PPWSA

Table 4.3.33 Impacts of COVID-19

Item	Handling
Water demand forecast without Group 1,2, and 3	Have much effect by the COVID-19
Water demand forecast of Group 1,2 and 3	Not much effect

Source: JICA Data Collection Survey Team

Three case studies were considered, as shown in ***Figure 4.3.22***. These three cases were applied to the water demand forecast. The results are shown in ***Figure 4.3.23*** and ***Table 4.3.34***.



Case 0: Water demand forecast by this study without Group 1,2 and 3.
Case 1: Demand is recovered toward 2030.
Case 2: Demand is delayed for 3 years compared to Case 0.
Case 3: Intermediate of Case 1 and Case 2.

Figure 4.3.22 Case study to handle the impact of COVID-19
Source: JICA Data Collection Survey Team

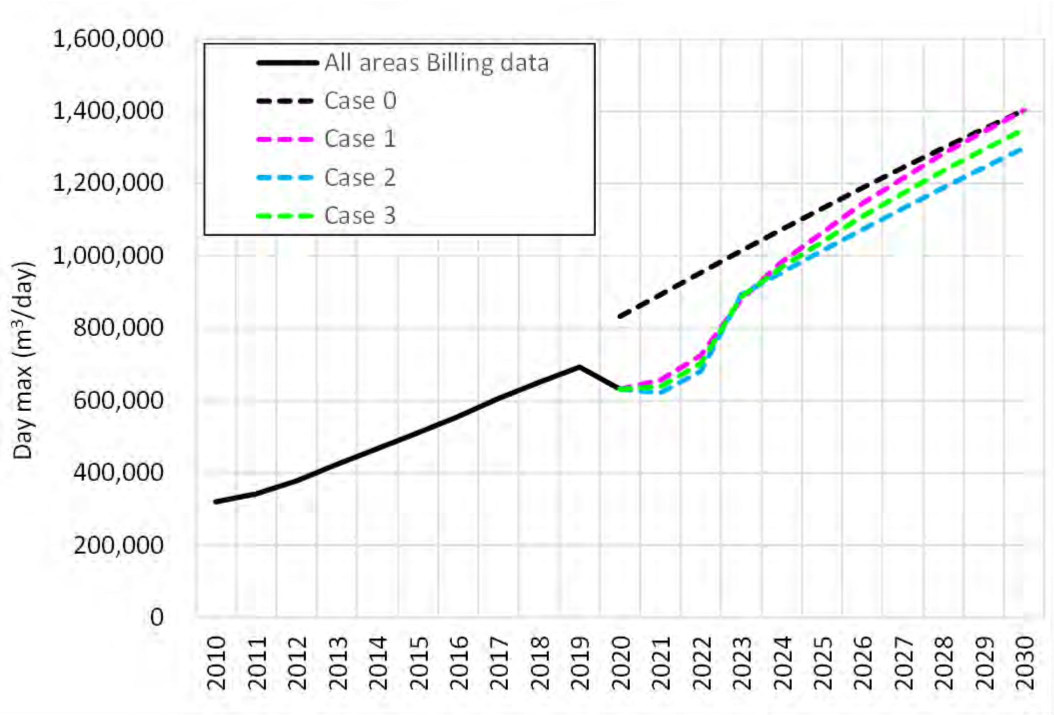


Figure 4.3.23 Results of Water Demand Forecast Reflecting the Effects of COVID-19
Source: JICA Data Collection Survey Team

Table 4.3.34 Results of Water Demand Forecast Reflecting the Effects of COVID-19

Unit: m^3/day

Item		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
MDD	1. Case 0	893,000	954,000	1,014,000	1,073,000	1,132,000	1,189,000	1,244,000	1,298,000	1,351,000	1,403,000
	2. Case 1	657,000	725,000	880,000	983,000	1,064,000	1,146,000	1,214,000	1,283,000	1,343,000	1,403,000
	3. Case 2	622,000	682,000	893,000	954,000	1,014,000	1,073,000	1,132,000	1,189,000	1,244,000	1,298,000
	3. Case 3	640,000	703,000	887,000	969,000	1,039,000	1,110,000	1,173,000	1,236,000	1,294,000	1,351,000

Source: JICA Data Collection Survey Team

Case 1 is selected for the water demand forecast for the following reasons:

- Many foreigners and people from rural areas are expected to come back after the end of COVID-19.
- Developments and construction works are progress in the entire Phnom Penh City.

4.3.9 Results of Water Demand Forecast

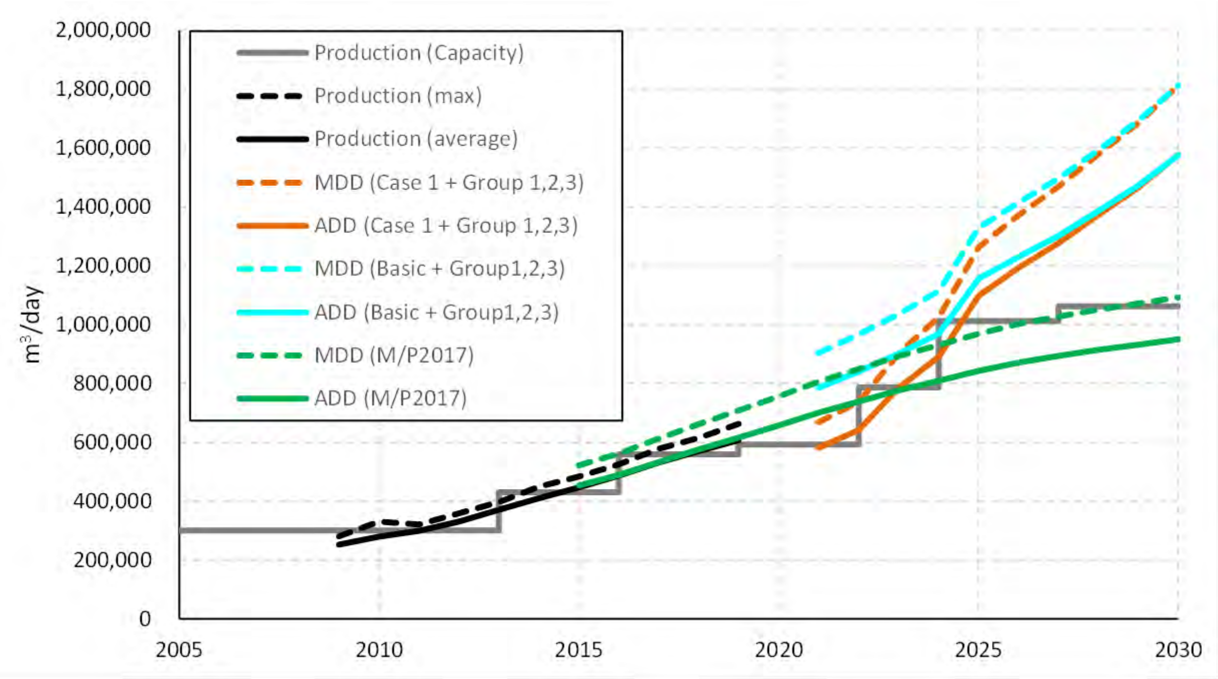
The results of the water demand forecast considering the impact of COVID-19 are as shown in ***Table 4.3.35*** and ***Figure 4.3.24***.

Table 4.3.35 Water demand forecast

Unit: m^3/day

Item		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
ADD	1. Case 1 (Basic)	571,157	630,019	765,103	854,704	924,707	996,034	1,055,602	1,115,097	1,167,589	1,219,600
	2. Group 1	9,547	11,684	20,075	35,734	46,503	61,867	76,554	103,959	135,798	183,739
	3. Group 2	0	0	0	0	62,558	67,564	72,570	77,570	82,576	88,748
	4. Group 3	0	0	0	0	63,696	67,942	72,188	76,436	80,681	84,928
	5. Total	581,000	642,000	786,000	891,000	1,098,000	1,194,000	1,277,000	1,374,000	1,467,000	1,578,000
MDD	1. Case 1 (Basic)	656,830	724,523	879,869	982,911	1,063,413	1,145,438	1,213,942	1,282,364	1,342,726	1,402,540
	2. Group 1	10,978	13,437	23,086	41,095	53,481	71,146	88,036	119,554	156,168	211,305
	3. Group 2	0	0	0	0	71,937	77,691	83,450	89,200	94,958	102,059
	4. Group 3	0	0	0	0	73,250	78,133	83,016	87,901	92,783	97,667
	5. Total	668,000	738,000	903,000	1,025,000	1,263,000	1,373,000	1,469,000	1,580,000	1,687,000	1,814,000

Source: JICA Data Collection Survey Team



*Basic: Water demand which does not consider the impacts of COVID-19

Figure 4.3.24 Water Demand Forecast

Source: JICA Data Collection Survey Team

CHAPTER 5 WATER RESOURCES

5.1 EXISTING CONDITIONS

5.1.1 General

Entire map of the coverage area of this study is shown in ***Figure 5.1.1***.

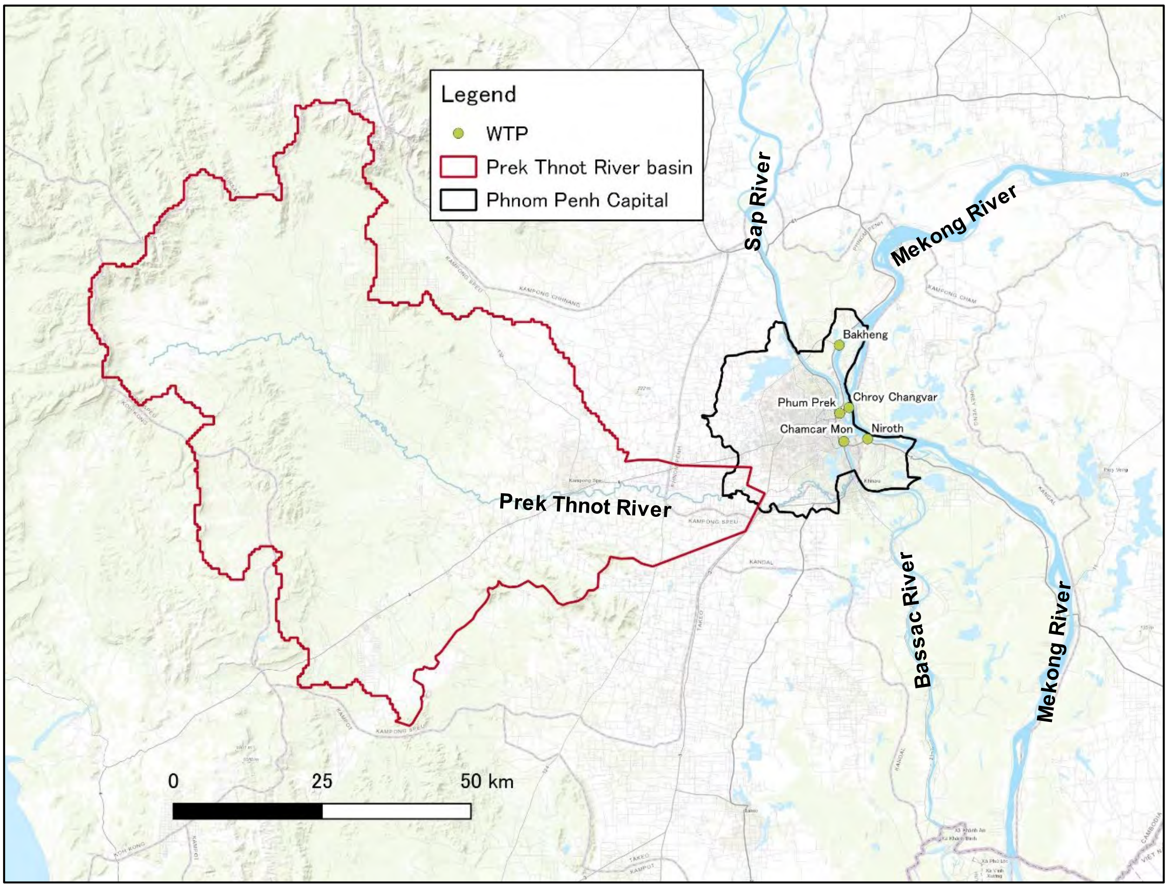


Figure 5.1.1 Entire Map of the Coverage Area for Water Resource
Source: JICA Data Collection Survey Team

Phnom Penh area and locations of WTP are shown in ***Figure 5.1.2***.

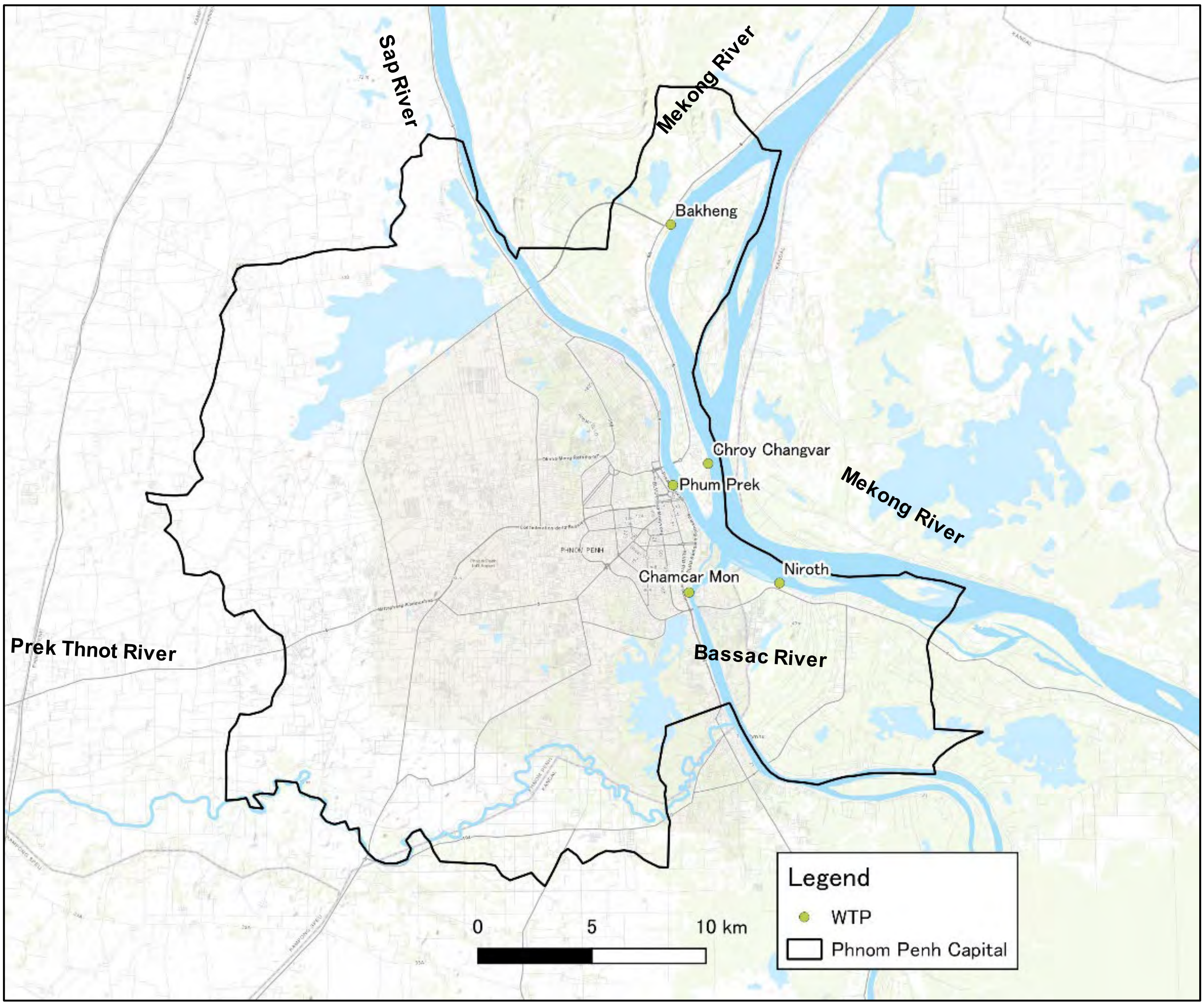


Figure 5.1.2 Location Map of Candidate Water Resource for the Phnom Penh Capital
Source: JICA Data Collection Survey Team

PPWSA has four water sources: the Mekong River, Sap River, Bassac River, and Prek Thnot River. In addition, dams on the Prek Thnot River and groundwater are also potential water sources. Possible water sources are outlined in ***Table 5.1.1***.

Table 5.1.1 Rivers and Basins as Possible Water Source

WATER SOURCE	TYPE OF SOURCE	GENERAL FEATURE	GEOGRAPHYCAL CHARACTERISTICS
Mekong River upstream	Surface water	Abundant quantity, good quality throughout the year	North-eastern part (borders Kandal Stung Province), approx. 20 km river section
Mekong River downstream	Surface water	Abundant quantity, good quality throughout the year	South-eastern part (borders Kandal Stung Province), approx. 15 km river section
Sap River	Surface water	Adequate quantity, fair quality throughout the year	Northern part (inside Phnom Penh and in Kandal Stung Province), approx. 20 km river section
Bassac River	Surface water	Fair quantity, poor quality throughout the year	South-eastern part (inside Phnom Penh and in Kandal Stung Province), approx.20 km river section
Prek Thnot River	Surface water	Poor quantity in dry season, poor quality in dry season	Southern part (borders Kandal Stung Province), approx. 30 km river section, irrigation facilities located
Dams in the Prek Thnot River basin	Surface water (carried by aqueduct from dam reservoir)	Abundant quantity and good quality but difficulty to allocate water for non-irrigation purposes Located in remote area and aqueduct required.	West of Phnom Penh Capital (in Kampong Spue Province), catchment area: 5,070 km^2, maximum elevation: 1,600 m

WATER SOURCE	TYPE OF SOURCE	GENERAL FEATURE	GEOGRAPHYCAL CHARACTERISTICS
Groundwater	Deep well abstraction	Available in peri-urban area, limited quantity, good quality but often high iron content	Inside Phnom Penh Capital (679 km^2)

Source: JICA Data Collection Survey Team

The water sources of the existing WTPs in Phnom Penh consist of three rivers: the Sap River, Mekong River, and Bassac River. The current intake volume rate at each WTP is as shown in ***Table 5.1.2***.

Table 5.1.2 Current Raw Water Intake Rate

WTP	WATER SOURCE	MAXIMUM INTAKE RATE in 2019	INTAKE TYPE	CONDITION
Phum Prek	Sap River	202,027 m^3/day	Direct Intake Tower	Aged and deteriorated
Chroy Changvar	Mekong River	193,900 m^3/day	Direct Intake Tower	Good
Nirodh	Mekong River	316,230 m^3/day	Tower with Extended Intake Pipe	Good
Chamcar Mon	Bassac River	59,030 m^3/day	Tower with Extended Intake Pipe	New and good
WATER SOURCE		**MAXIMUM INTAKE RATE (RIVER SUB-TOTAL)**	**MINIMUM RIVER FLOW RATE (Sap: MEAN FLOW RATE)**	**% OF INTAKE RATE PER RIVER FLOW RATE**
Sap River		202,027 m^3/day	70,156,800 m^3/day	0.29%
Mekong River		510,130 m^3/day	224,640,000 m^3/day	0.23%
Bassac River		59,030 m^3/day	3,456,000 m^3/day	1.71%
TOTAL		771,187 m^3/day		

Source: PPWSA

River water levels at each intake are summarized in the ***Table 5.1.3*** below.

Table 5.1.3 River Water Level

WTP	WATER SOURCE	RECORD PERIOD	RIVER WATER LEVEL (AMSL*1)		
			MAXIMUM	AVERAGE	MINIMUM
Phum Prek	Sap River	Jan. 2005 – Oct. 2020	+9.61 m	+4.19 m	+1.42 m
Chroy Changvar	Mekong River	Jan. 2009 – Oct. 2020	+10.00 m	+4.59 m	+1.03 m
Nirodh	Mekong River	Jan. 2014 – Oct. 2020	+8.41 m	+3.10 m	+0.76 m
Chamcar Mon	Bassac River	Nov. 2019 – Oct. 2020	+6.73 m	+1.94 m	+0.35 m

Note) *1: AMSL means Above Mean Seawater Level.
Source: PPWSA

Details of flow rate and water level of these rivers are discussed in the following sections.

General raw water quality summarized from the recorded raw water quality at each intake of existing WTPs is as shown in ***Table 5.1.4***.

Table 5.1.4 General Raw Water Quality

NO.	PARAMETER	UNIT	GENERAL RAW WATER QUALITY (RANGE)				NDWQS*1 (TREATED)
			PHUM PREK	CHROY CHANGVAR	NIRODH	CHAMCAR MON	
1	Temperature	°C	25.3-31.5	23.7-32.7	25.4-32.5	25.2-31.2	
2	pH	-	6.78-7.99	7.17-8.48	7.05-8.24	6.88-8.11	6.5-8.5
3	Turbidity	NTU	12-427	10-469	14-379	8-799	<5
4	Conductivity	µs/cm	62-258	83-259	70-259	72-259	<1600
5	Suspended Solids (SS)	mg/L	10-404	6-439	11-359	6-532	
6	TDS	mg/L	31-147	42-161	9-130	36-130	<800
7	Total Coliform	cfu/100ml	825-366175	505-116000	300-91640	400-458100	
8	E. Coli	cfu/100ml	130-108050	43-10825	0-13210	36-11867	0
9	Ca hardness	mg/L	11-66	17-65	20-70	12-70	
10	Total Hardness	mg/L	23-104	31-98	18-108	24-116	<300
11	Mg hardness	mg/L	6-38	8-41	6-40	4-46	

NO.	PARAMETER	UNIT	GENERAL RAW WATER QUALITY (RANGE)				NDWQS[*1] (TREATED)
			PHUM PREK	CHROY CHANGVAR	NIRODH	CHAMCAR MON	
12	Alkalinity	mg/L	23-78	27-80	30-88	24-79	
13	Organic substance	mg/L	6.32-35.88	2.35-29.99	2.38-27.01	2.9-30.39	
14	DO	mg/L	1.76-7.18	4.53-8.68	5.74-11.09	6.18-8.5	
15	Color	mg/L Pt	4.53-147.11	1.98-228	3.58-121.2	4.91-182	<5
16	UV absorption	-	0.006-1.023	0.003-0.403	0.01-0.292	0.007-1.134	
17	Aluminum (Al)	mg/L	0-0.082	0-0.193	0-1.21	0-0.11	<0.2
18	Ammonia (NH_3)	mg/L	0-2.81	0-2.78	0-2.59	0-1.81	
19	NH_4-N	mg/L	0-2.3	0-3.39	0-2.12	0-1.48	<1.5
20	Carbon dioxide (CO_2)	mg/L	1.5-42	0-17	0-13	1-21	
21	Copper (Cu)	mg/L	0-0.1	0-0.12	0-0.11	0-0.11	<1
22	Chloride (Cl^-)	mg/L	1-55	4.8-52	13-46	7.4-50	<250
23	Cyanide (CN^-)	mg/L	0-0.02	0-0.04	0.001-0.009	0-0.03	<0.07
24	Chromium total (Cr)	mg/L	0-0.05	0-0.08	0-0.09	0-0.03	
25	Chromium hexa (Cr^{6+})	mg/L	0-0.09	0-0.05	0-0.1	0-0.03	<0.05
26	Fluoride (F^-)	mg/L	0-1.14	0-1.21	0-0.57	0-0.48	<1.5
27	Iron (Fe)	mg/L	0-1.14	0-8.12	0.018-2.64	0-6.88	<0.3
28	Manganese (Mn)	mg/L	0-0.3	0-0.33	0-1.2	0-0.23	<0.1
29	NO_3-N	mg/L	0.33-7.8	0-2.4	0-5.31	0-3.54	
30	Nitrate (NO_3)	mg/L	1.5-13.7	0-10.608	0-7.07	0-11.49	<50
31	NO_2-N	mg/L	0.002-0.147	0-0.11	0-0.08	0-0.09	
32	Nitrite (NO_2)	mg/L	0.0029-0.482	0-0.3608	0-0.098	0-0.164	<3
33	Zinc (Zn)	mg/L	0-0.28	0-0.2	0-0.11	0-0.17	<3
34	Phosphate (PO_4^{3-})	mg/L	0-1.98	0.01-0.54	0.005-0.64	0.01-1.5	
35	Sulphide (S^{2-})	mg/L	0-0.098	0-0.06	0-0.05	0-0.33	
36	Sulphate (SO_4^{2-})	mg/L	0-32	0-30	0-30	0-34	<250

Note) *1: NDWQS means National Drinking Water Quality Standards prepared by MISTI (MIH) in 2015.
Source: PPWSA

5.1.2 Water Sources Options

(1) Mekong River

1) Water Level of Mekong River

Average daily water level of the Mekong River at Chroy Changvar station is shown in ***Figure 5.1.3***. Water level frequency of Mekong River at Chroy Changvar is also shown in ***Figure 5.1.4***.

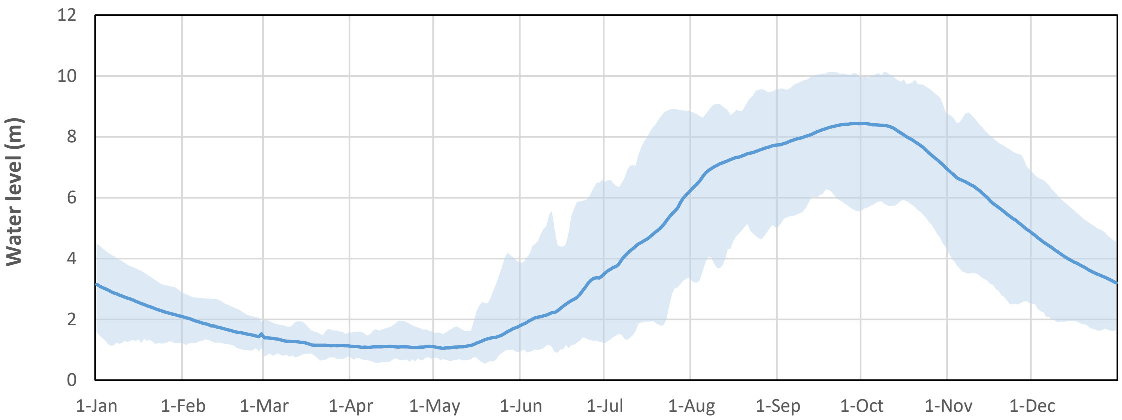


Figure 5.1.3 Mekong River Water Level at Chroy Changvar (Daily Average of 1996-2017)
Source: JICA Survey Team (2021) based on the data from Department of Hydrology and River Works (DHRW), MOWRAM

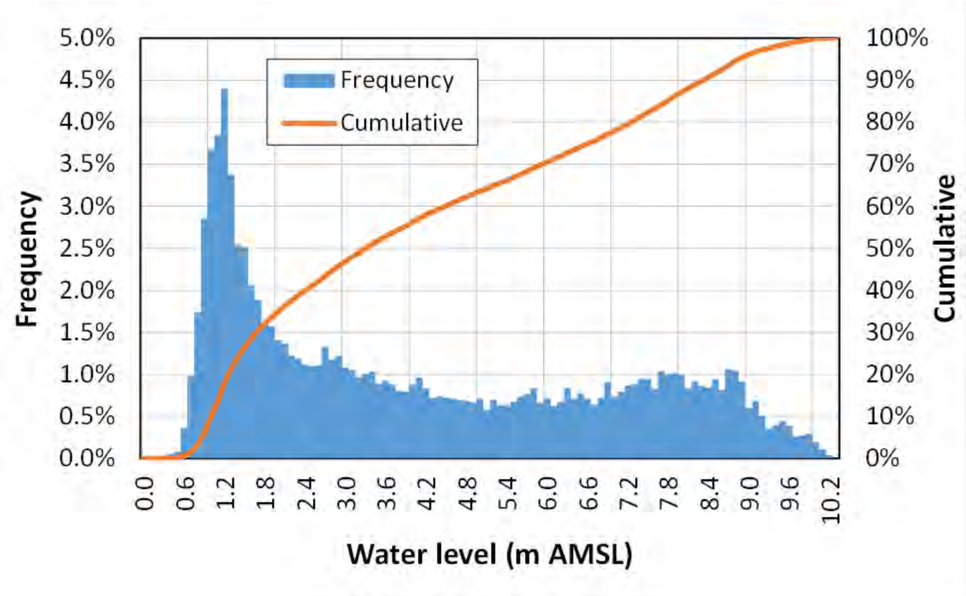
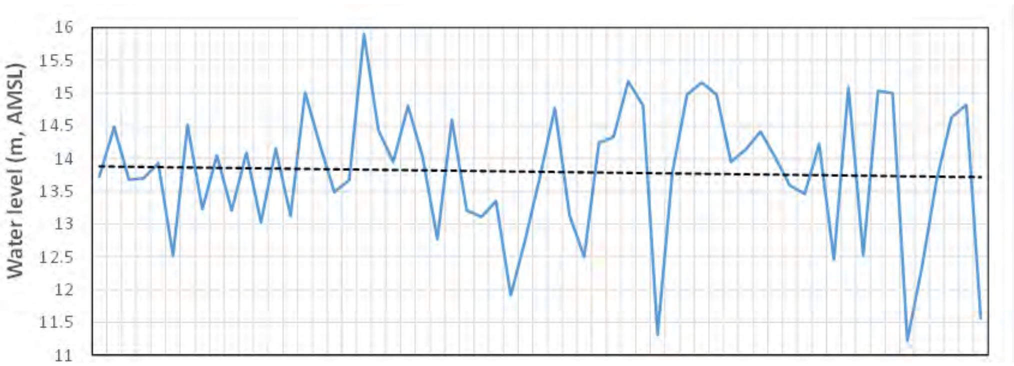


Figure 5.1.4 Water Level Frequency of Mekong River at Chroy Changvar
Source: JICA Survey Team (2021) based on the data from DHRW, MOWRAM

Based on these data, average and extreme levels are as follows:

- ✓ Average water level: 4.05 m AMSL
- ✓ Average annual maximum water level: 8.79 m AMSL
- ✓ Average annual minimum water level: 0.72 m AMSL
- ✓ Maximum high water level: 10.15 m AMSL (09/10/2011)
- ✓ Minimum low water level: 0.14 m AMSL (04/05/1960)
- ✓ 99.9% of observed water level is more than 0.42 m AMSL
- ✓ 99% of observed water level is more than 0.65 m AMSL
- ✓ 1 % of observed water level is more than 9.67 m AMSL
- ✓ 0.1 % of observed water level is more than 10.2 m AMSL

Recent annual maximum high water level and annual minimum low-water level of the Mekong River are shown in ***Figure 5.1.5***. Since water level data at Chroy Changvar station are not available for the past three years, water level at Kampong Cham station which is upstream are shown here. The maximum high water level has a decreasing trend, while the minimum low water level is slightly increasing. It suggests that there might be almost same trend in the water level of the Mekong River around Phnom Penh.



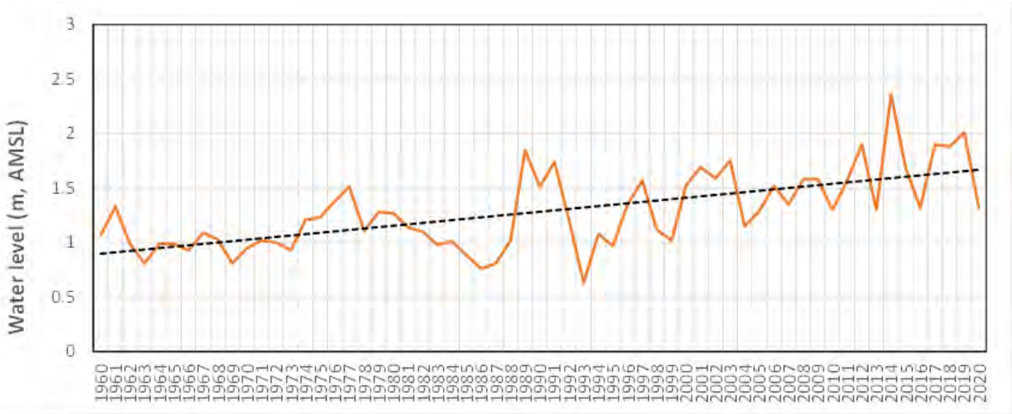


Figure 5.1.5 Trend of Annual Maximum High Water Level and Annual Minimum Low Water Level of Mekong River at Kampong Cham (1996-2020)

Source: JICA Survey Team (2021) based on the data from DHRW, MOWRAM

In recent years, due to the start of construction and operation of hydropower dams in the upper stream of the Mekong River and changes in rainfall characteristics due to climate change, the water levels of the Mekong and Sap rivers around Phnom Penh have been observed. ***Figure 5.1.7*** shows the long-term change of the Mekong River water level in the dry season at Kampong Cham. In recent years, the water level has dropped to a record level during the dry season of 2019-2020.

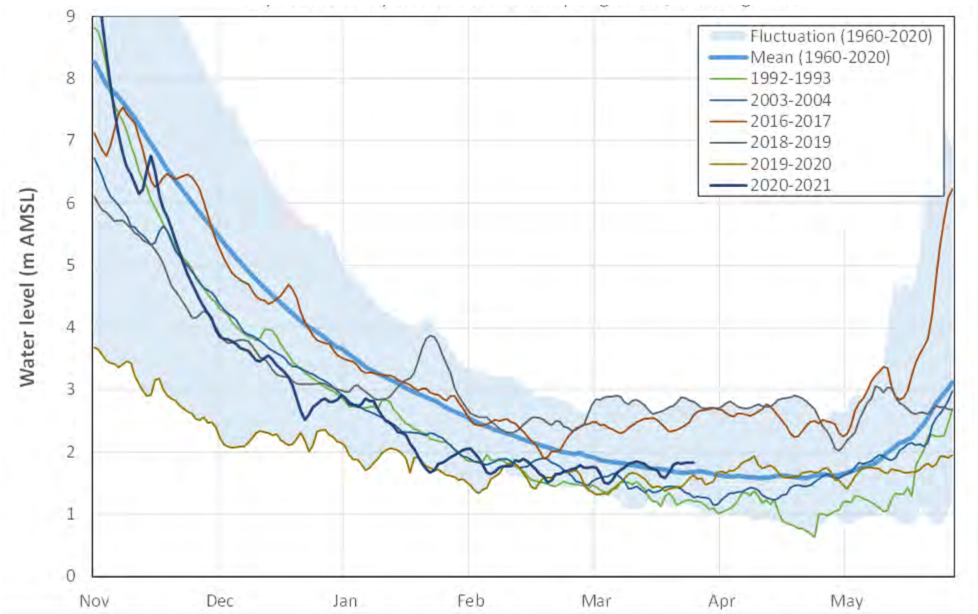


Figure 5.1.6 Annual Trend of Water Level of Mekong River at Kampong Cham (Dry Season Only, 1996-2020)

Source: JICA Survey Team (2021) based on the data from DHRW, MOWRAM

Water level decline due to dam operation and climate change impacts is very important information in water source selection and intake facility design. Prediction of future changes by MRC in hydrological factors (precipitation, river water level, discharge, etc.) due to dams and climate change is described in ***5.2.3(1)***.

2) Flow Rate of Mekong River

Monthly average flow of the Mekong River at Chroy Changvar station is shown in ***Figure 5.1.7***. There is significant fluctuation depending on the season. The flow is adequate even at the minimum rate of 1,889 m^3/s (in April), which is equivalent to 163,209,600 m^3/day (163,210 MLD).

Required raw water intake of 858,000 m^3/day (assuming a 10% water treatment loss) corresponding to the water demand of Phnom Penh as 780,000 m^3/day (780 MLD), and accounts for only 0.53% of the average minimum flow of the Mekong River. Even assuming that all of the increase in the required water intake corresponding to the future increase in water demand of Phnom Penh (approx. +1,200,000 m^3/day) is taken from the Mekong River, it is at most 1.3% of the average annual minimum discharge. Therefore, it is expected that the Mekong River will be able to supply a sufficient quantity of water as a future water source for the Phnom Penh Capital.

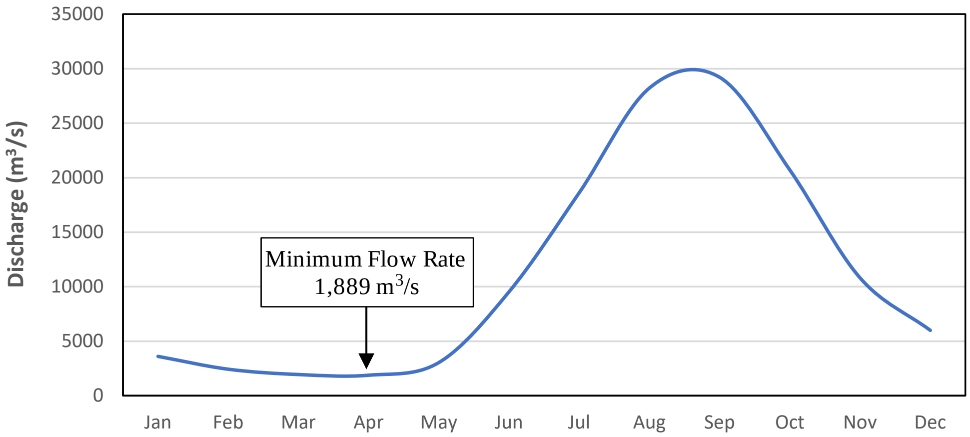


Figure 5.1.7 Mekong River Flow Rate at Chroy Changvar (Monthly Average of 1960-2017)
Source: DHRW, MOWRAM

3) Water Quality of Mekong River

Water quality at Chroy Changvar intake was tested as shown in ***Table 5.1.5***. Major parameters are within the normal range. Here, based on actual flow rate of river, dry season and wet season are defined as from January to May, and from June to December, respectively. Since Nirodh WTP is also in the Mekong River, water quality at Nirodh intake is also shown in ***Table 5.1.6***.

Table 5.1.5 Water Quality of Mekong River at Chroy Changvar WTP Intake

NO.	PARAMETER	UNIT	RAW WATER QUALITY (RANGE)			NDWQS[*1] (TREATED)
			OVERALL AVE. (RANGE)	DRY SEASON (AVE.)	WET SEASON (AVE.)	
1	Temperature	°C	28.9 (23.7-32.7)	29.1	28.7	
2	pH	-	7.86 (7.17-8.48)	8.08	7.69	6.5-8.5
3	Turbidity	NTU	110.6 (10-469)	18.7	177.4	<5
4	Conductivity	μs/cm	160.0 (83-259)	193.3	135.8	<1600
5	Suspended Solids (SS)	mg/L	94.7 (6-439)	14.6	153.0	
6	TDS	mg/L	80.7 (42-161)	96.7	69.1	<800
7	Total Coliform	cfu/100ml	6534 (505-116000)	4070	8329	
8	E. Coli	cfu/100ml	1077 (43-10825)	717	1340	0
9	Ca hardness	mg/L	44.5 (17-65)	53.4	38.0	
10	Total Hardness	mg/L	65.1 (31-98)	79.1	55.0	<300
11	Mg hardness	mg/L	20.8 (8-41)	25.9	17.0	
12	Alkalinity	mg/L	57.6 (27-80)	70.0	48.7	
13	Organic substance	mg/L	10.5 (2.35-29.99)	7.32	12.8	
14	DO	mg/L	7.33 (4.53-8.68)	7.34	7.32	
15	Color	mg/L Pt	30.8 (1.98-228)	7.71	47.7	<5
16	UV absorption	-	0.10 (0.003-0.403)	0.045	0.15	
17	Aluminum (Al)	mg/L	0.048 (0-0.193)	0.051	0.045	<0.2
18	Ammonia (NH_3)	mg/L	0.26 (0-2.78)	0.12	0.37	
19	NH_4-N	mg/L	0.23 (0-3.39)	0.09	0.32	<1.5
20	Carbon dioxide (CO_2)	mg/L	4.16 (0-17)	3.81	4.42	
21	Copper (Cu)	mg/L	0.023 (0-0.12)	0.025	0.022	<1
22	Chloride (Cl^-)	mg/L	22.2 (4.8-52)	21.8	22.4	<250
23	Cyanide (CN^-)	mg/L	0.003 (0-0.04)	0.002	0.003	<0.07
24	Chromium total (Cr)	mg/L	0.019 (0-0.08)	0.019	0.020	
25	Chromium hexa (Cr^{6+})	mg/L	0.012(0-0.05)	0.011	0.012	<0.05
26	Fluoride (F^-)	mg/L	0.18 (0-1.21)	0.20	0.16	<1.5
27	Iron (Fe)	mg/L	0.37 (0-8.12)	0.062	0.59	<0.3
28	Manganese (Mn)	mg/L	0.034 (0-0.33)	0.032	0.035	<0.1
29	NO_3-N	mg/L	0.90 (0-2.4)	0.74	1.02	

NO.	PARAMETER	UNIT	RAW WATER QUALITY (RANGE)			NDWQS[*1] (TREATED)
			OVERALL AVE. (RANGE)	DRY SEASON (AVE.)	WET SEASON (AVE.)	
30	Nitrate (NO_3)	mg/L	3.92 (0-10.608)	3.24	4.42	<50
31	NO_2-N	mg/L	0.010 (0-0.11)	0.010	0.009	
32	Nitrite (NO_2)	mg/L	0.030 (0-0.3608)	0.031	0.029	<3
33	Zinc (Zn)	mg/L	0.049 (0-0.2)	0.048	0.050	<3
34	Phosphate (PO_4^{3-})	mg/L	0.14 (0.01-0.54)	0.14	0.15	
35	Sulphide (S^{2-})	mg/L	0.010 (0-0.06)	0.005	0.013	
36	Sulphate (SO_4^{2-})	mg/L	11.1 (0-30)	15.49	7.94	<250

Source: PPWSA

Table 5.1.6 Water Quality of Mekong River at Nirodh WTP Intake

NO.	PARAMETER	UNIT	RAW WATER QUALITY			NDWQS[*1] (TREATED)
			OVERALL AVE. (RANGE)	DRY SEASON (AVE.)	WET SEASON (AVE.)	
1	Temperature	ºC	28.8 (25.4-32.5)	29.1	28.6	
2	pH	-	7.64 (7.05-8.24)	7.8	7.5	6.5-8.5
3	Turbidity	NTU	82.5 (14-379)	22.0	127.7	<5
4	Conductivity	μs/cm	159.2 (70-259)	199.3	129.3	<1600
5	Suspended Solids (SS)	mg/L	71.1 (11-359)	17.4	111.0	
6	TDS	mg/L	78.7 (9-130)	97.4	64.8	<800
7	Total Coliform	cfu/100ml	5742 (300-91640)	4926	6349	
8	E. Coli	cfu/100ml	531 (0-13210)	358	661	0
9	Ca hardness	mg/L	41.6 (20-70)	50.9	34.7	
10	Total Hardness	mg/L	59.7 (18-108)	72.2	50.3	<300
11	Mg hardness	mg/L	19.6 (6-40)	24.6	15.9	
12	Alkalinity	mg/L	53.8 (30-88)	65.5	45.0	
13	Organic substance	mg/L	12.3 (2.38-27.01)	10.7	13.5	
14	DO	mg/L	7.33 (5.74-11.09)	7.25	7.38	
15	Color	mg/L Pt	30.2 (3.58-121.2)	13.7	42.4	<5
16	UV absorption	-	0.099 (0.01-0.292)	0.06	0.13	
17	Aluminum (Al)	mg/L	0.054 (0-1.21)	0.023	0.078	<0.2
18	Ammonia (NH_3)	mg/L	0.39 (0-2.59)	0.21	0.53	
19	NH_4-N	mg/L	0.33 (0-2.12)	0.17	0.45	<1.5
20	Carbon dioxide (CO_2)	mg/L	2.89 (0-13)	2.28	3.34	
21	Copper (Cu)	mg/L	0.019 (0-0.11)	0.024	0.015	<1
22	Chloride (Cl^-)	mg/L	27.7 (13-46)	27.5	27.9	<250
23	Cyanide (CN^-)	mg/L	0.002 (0.001-0.009)	0.003	0.002	<0.07
24	Chromium total (Cr)	mg/L	0.023 (0-0.09)	0.022	0.024	
25	Chromium hexa (Cr^{6+})	mg/L	0.014 (0-0.1)	0.013	0.015	<0.05
26	Fluoride (F^-)	mg/L	0.15 (0-0.57)	0.19	0.12	<1.5
27	Iron (Fe)	mg/L	0.54 (0.018-2.64)	0.25	0.75	<0.3
28	Manganese (Mn)	mg/L	0.041 (0-1.2)	0.019	0.058	<0.1
29	NO_3-N	mg/L	0.73 (0-5.31)	0.72	0.74	
30	Nitrate (NO_3)	mg/L	2.95 (0-7.07)	3.17	2.78	<50
31	NO_2-N	mg/L	0.008 (0-0.08)	0.011	0.006	
32	Nitrite (NO_2)	mg/L	0.026 (0-0.098)	0.029	0.023	<3
33	Zinc (Zn)	mg/L	0.030 (0-0.11)	0.030	0.030	<3
34	Phosphate (PO_4^{3-})	mg/L	0.20 (0.005-0.64)	0.19	0.20	
35	Sulphide (S^{2-})	mg/L	0.008 (0-0.05)	0.005	0.011	
36	Sulphate (SO_4^{2-})	mg/L	8.66 (0-30)	12.49	5.81	<250

Source: PPWSA

Chroy Changvar and Nirodh have similar water qualities, which are evaluated as follows:

- Favourable resource for water production, particularly during the dry season. pH allows proper flocculation despite quite low mineralisation.
- Turbidity is relatively low, oxygenation is relatively good, and bacteriological content is low.
- Chemical contamination levels are low.

Time series of main parameter on water quality at Chroy Changvar intake are shown from ***Figure 5.1.8*** to

***Figure 5.1.13**, and for Nirodh intake are shown from **Figure 5.1.14** to*

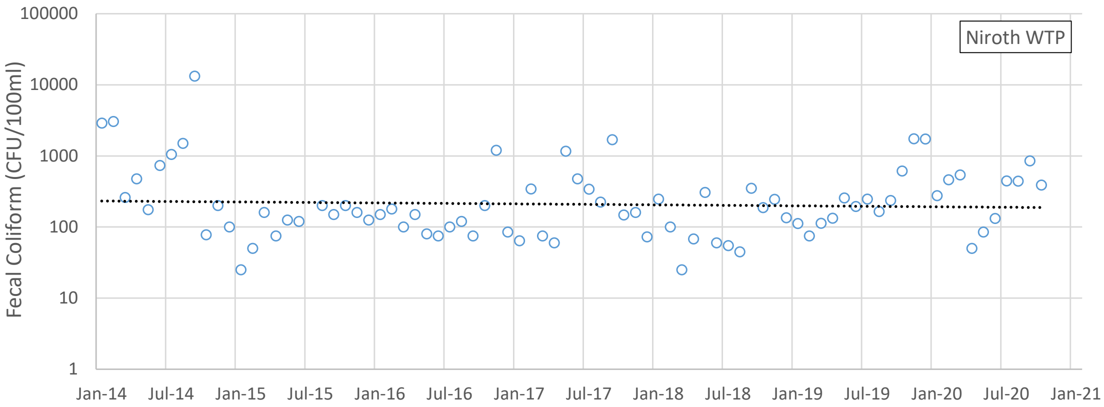


Figure 5.1.19. Long-term monitoring results since 2015 indicate no significant changes in water quality and no major issues as a water source.

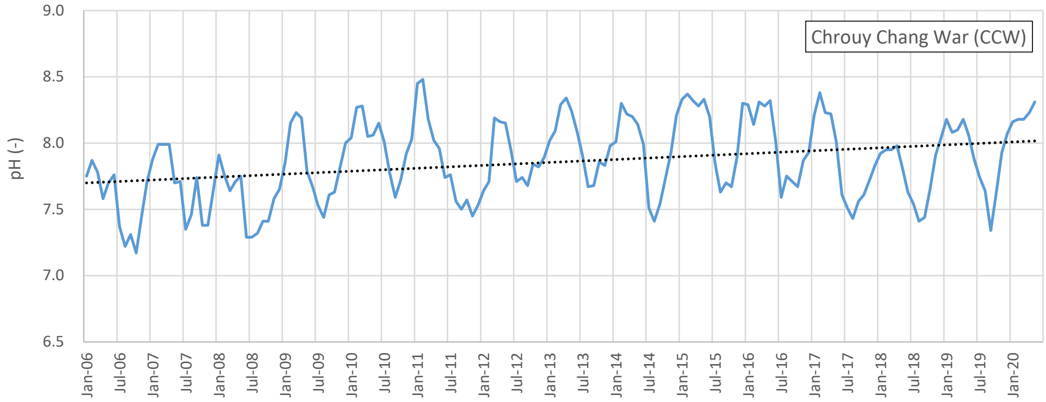


Figure 5.1.8 Long-term Changes of Water Quality at Chroy Changvar Water Intake (pH)
Source: PPWSA

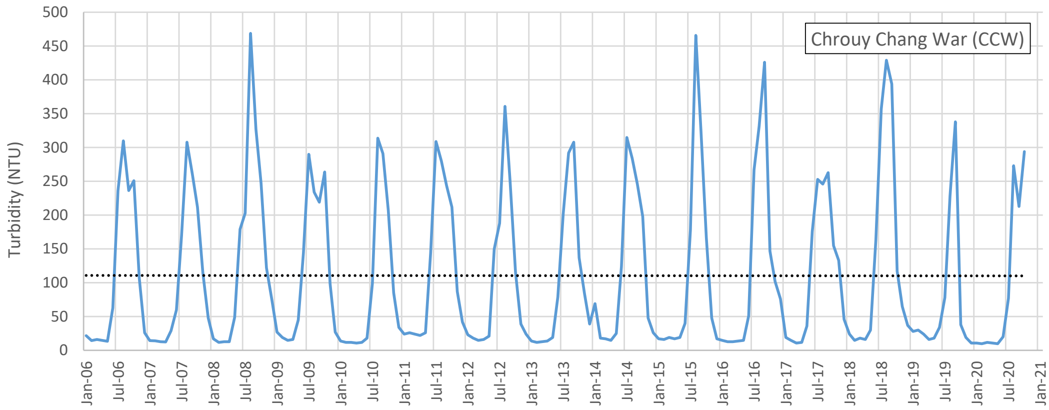


Figure 5.1.9 Long-term Changes of Water Quality at Chroy Changvar Water Intake (Turbidity)
Source: PPWSA

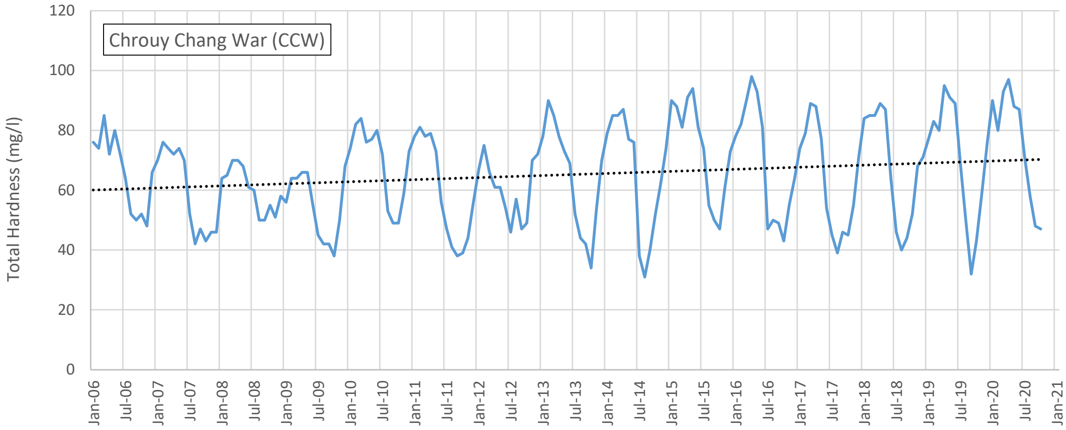


Figure 5.1.10 Long-term Changes of Water Quality at Chroy Changvar Water Intake (Total hardness)
Source: PPWSA

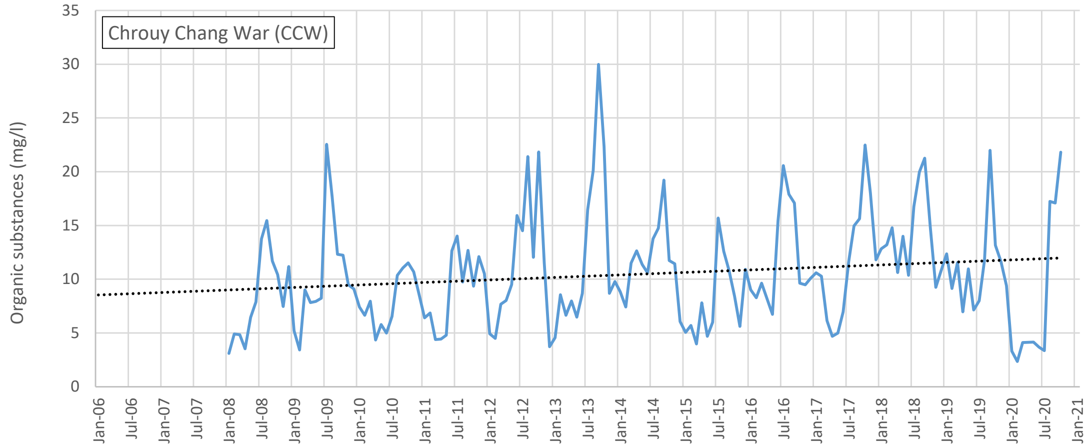


Figure 5.1.11 Long-term Changes of Water Quality at Chroy Changvar Water Intake (Organic substances)

Source: PPWSA

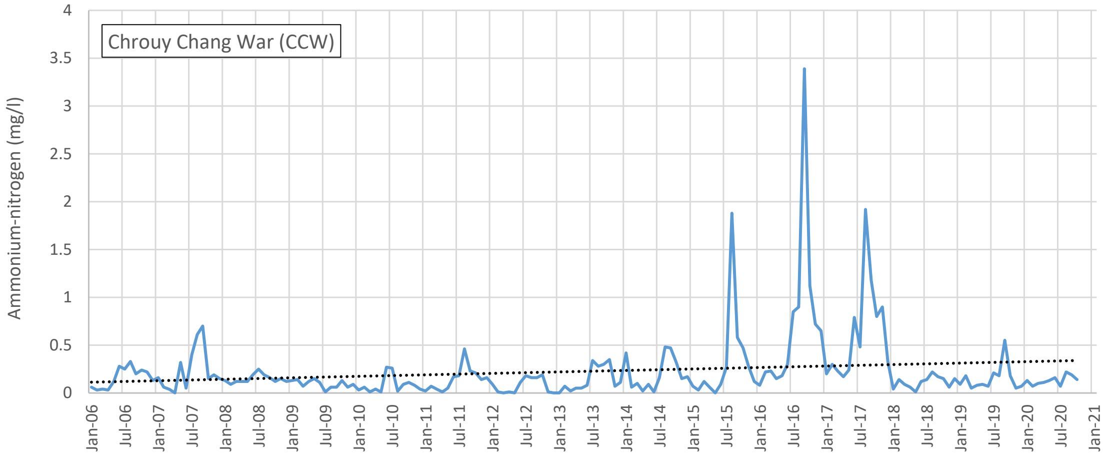


Figure 5.1.12 Long-term Changes of Water Quality at Chroy Changvar Water Intake (Ammonium-nitrogen)

Source: PPWSA

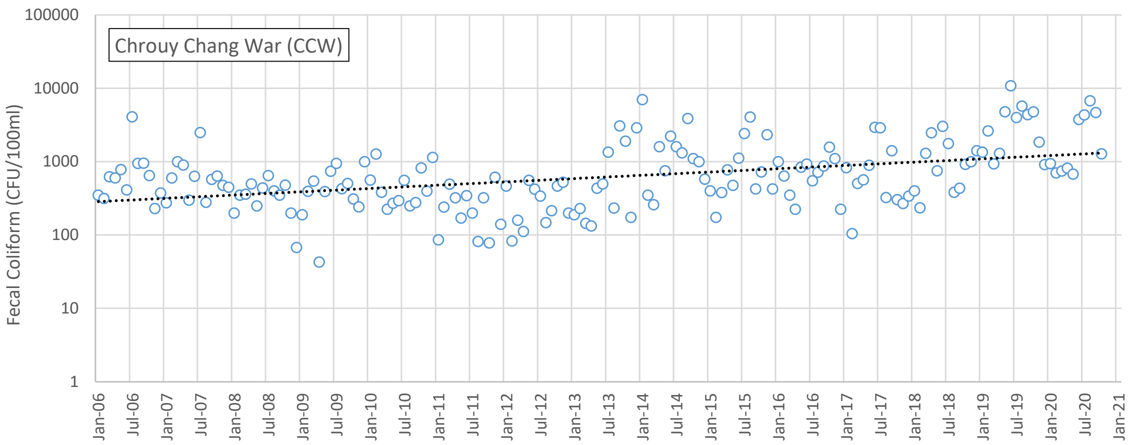


Figure 5.1.13 Long-term Changes of Water Quality at Chroy Changvar Water Intake (Fecal Choliforms)

Source: PPWSA

This long-term change indicates that there is no significant difference in water quality compared to the current quality. However, Fecal Coliform (E. Coli.) has an increasing trend since 2013. The following table summarises these findings.

Table 5.1.7 Trends of Change of Water Quality at Chroy Changvar WTP

TREND	PARAMETERS
Slight increase / constant	Ammonium, Turbidity, DO
Increase	Fecal Coliform (E. Coli), Total Hardness, Organic substances, Iron
Decrease	Nitrate
Strong decrease	-

Source: JICA Data Collection Survey Team

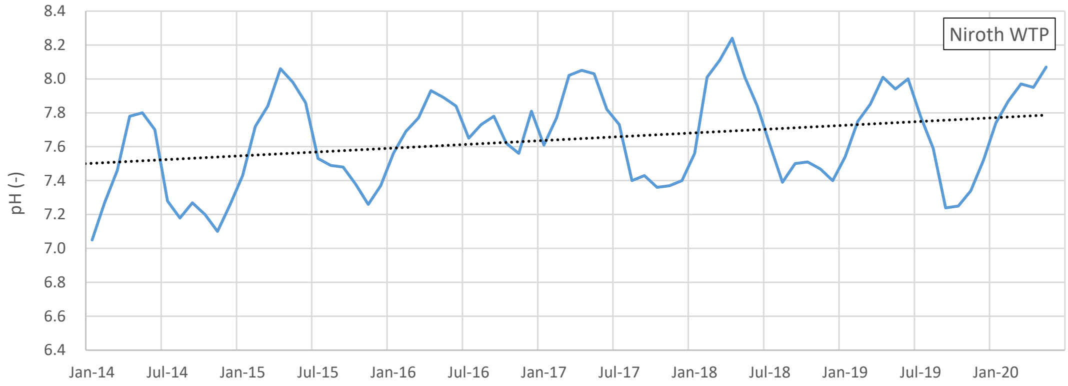


Figure 5.1.14 Long-term Changes of Water Quality at Nirodh Water Intake (pH)
Source: PPWSA

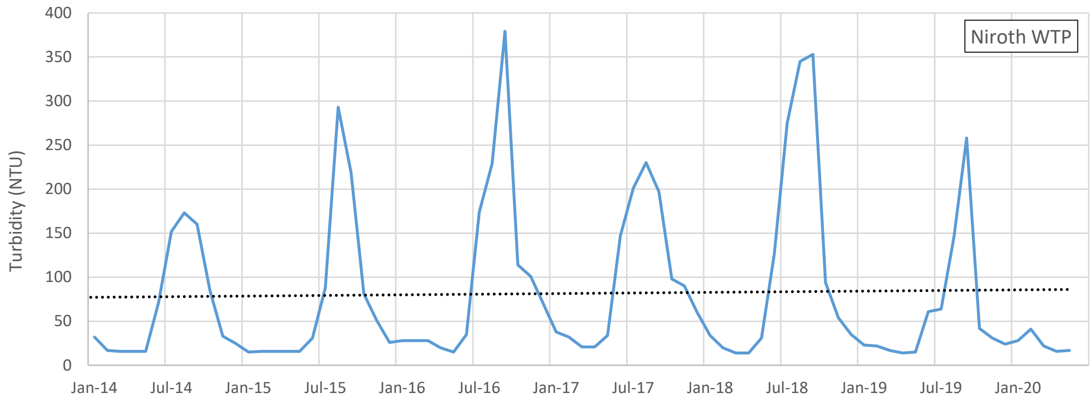


Figure 5.1.15 Long-term Changes of Water Quality at Nirodh Water Intake (Turbidity)
Source: PPWSA

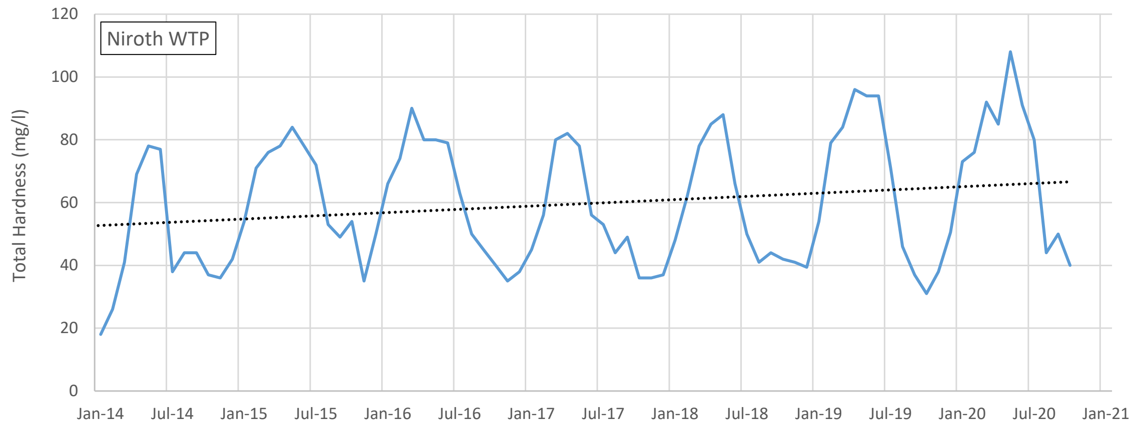


Figure 5.1.16 Long-term Changes of Water Quality at Nirodh Water Intake (Total Hardness)
Source: PPWSA

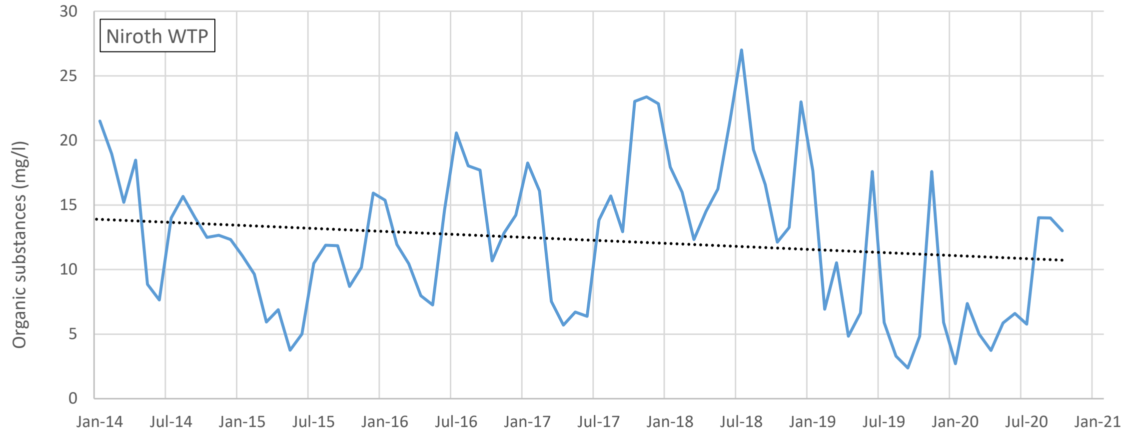


Figure 5.1.17 Long-term Changes of Water Quality at Nirodh Water Intake (Organic substances)
Source: PPWSA

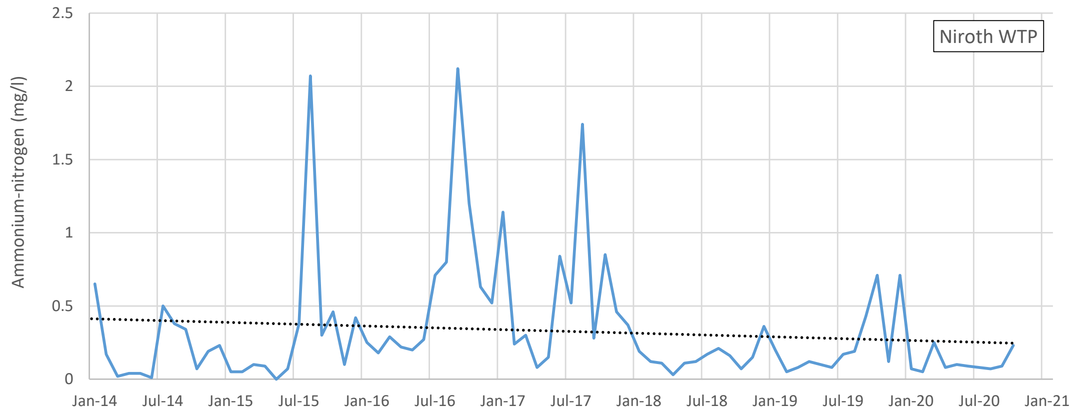


Figure 5.1.18 Long-term Changes of Water Quality at Nirodh Water Intake (Ammonium-nitrogen)
Source: PPWSA

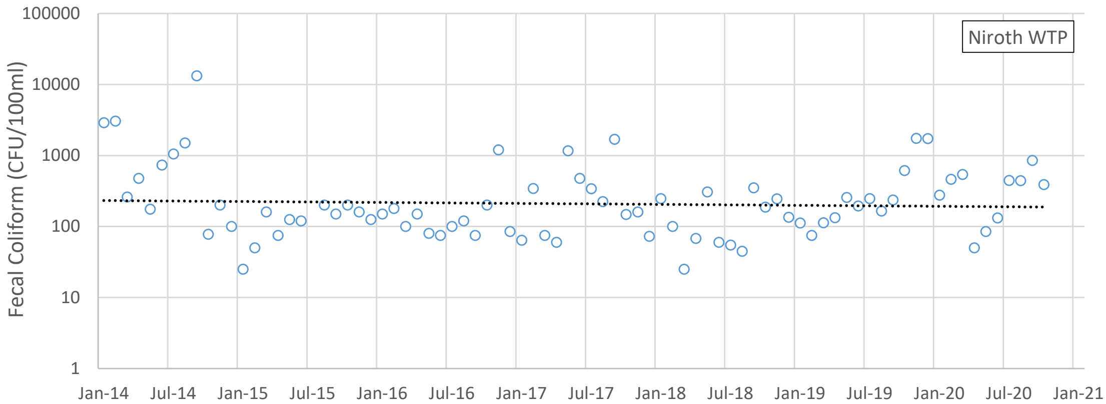


Figure 5.1.19 Long-term Changes of Water Quality at Nirodh Water Intake (Fecal Coliforms)
Source: PPWSA

This long-term change indicates that there is no significant difference in water quality compared to current conditions. However, total hardness has an increasing trend and organic substances has a decreasing trend. ***Table 5.1.8*** summarises these findings:

Table 5.1.8 Trends of Change of Water Quality at Nirodh WTP

TREND	PARAMETERS
Slight increase / constant	Ammonium, Turbidity, DO, Fecal Coliform (E. Coli), Iron, Nitrate
Increase	Total Hardness
Decrease	Organic substances
Strong decrease	-

Source: JICA Data Collection Survey Team

(2) Sap River

1) Water Level of Sap River

Average daily water level of Mekong River at Phnom Penh Port station is shown in ***Figure 5.1.20***. Water level frequency of Sap River at Phnom Penh Port is also shown in ***Figure 5.1.21***.

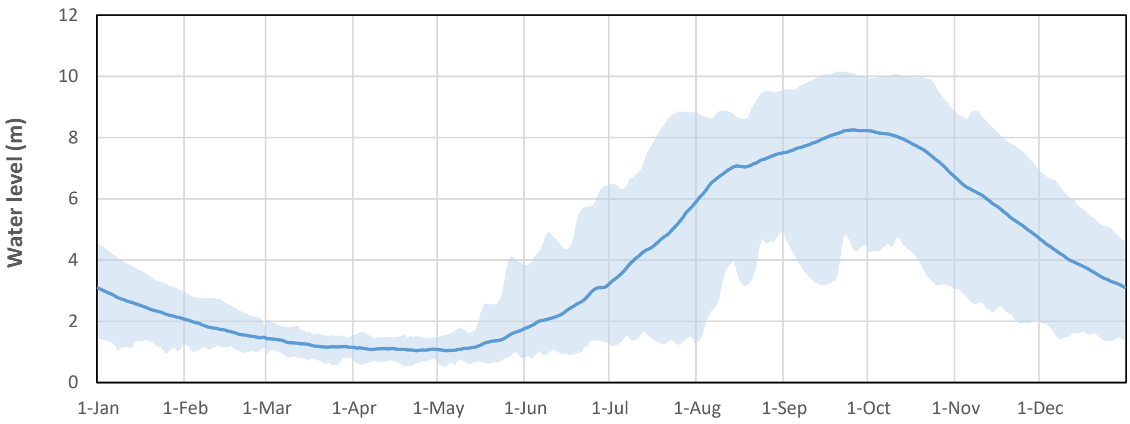


Figure 5.1.20 Sap River Water Level at Phnom Penh Port (Daily Average of 1960-2020)
Source: JICA Survey Team (2021) based on the data from DHRW, MOWRAM

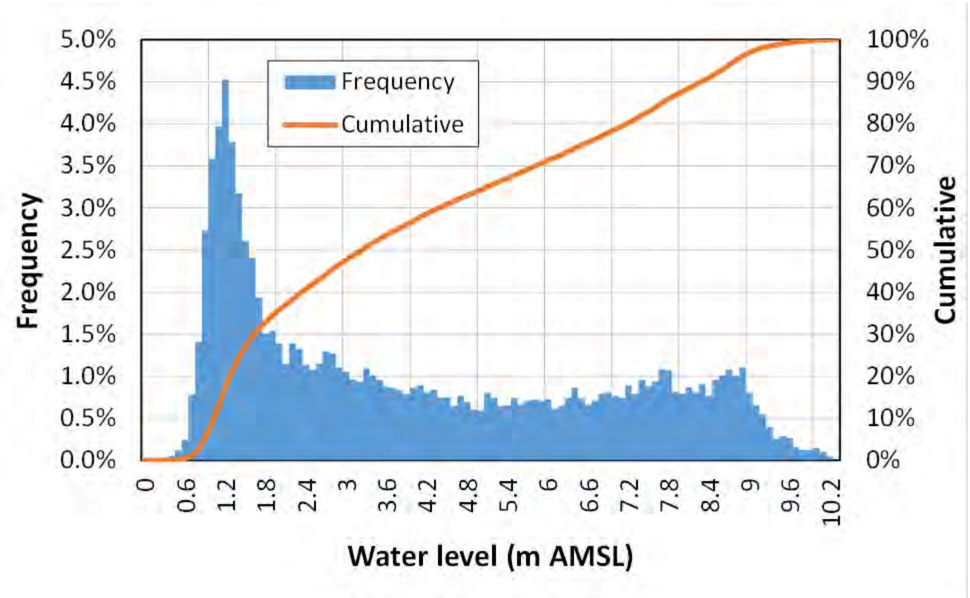


Figure 5.1.21 Water Level Frequency of Sap River at Phnom Penh Port
Source: JICA Survey Team (2021) based on the data from DHRW, MOWRAM

Based on these data, average and extreme levels are as follows:

- ✓ Average water level: 4.01 m AMSL
- ✓ Average annual maximum water level: 8.81 m AMSL
- ✓ Average annual minimum water level: 0.75 m AMSL
- ✓ Maximum high water level: 10.16 m AMSL (20/09/2000)

- ✓ Minimum low water level: 0.20 m AMSL (04/05/1960)
- ✓ 99.9% of observed water level is more than 0.43 m AMSL
- ✓ 99% of observed water level is more than 0.68 m AMSL
- ✓ 1 % of observed water level is more than 9.49 m AMSL
- ✓ 0.1 % of observed water level is more than 10.04 m AMSL

2) Flow Rate of Sap River

Monthly average flow of the Sap River at Prek Kdam station is shown in ***Figure 5.1.22***. The Sap River flows in opposite directions during the dry and wet seasons. During the dry season, the Sap River flows down to the water level of the Mekong River. In the wet season, water flows from the Mekong River to Tonle Sap Lake through the Sap River. Therefore, there is significant fluctuation of flow rate; that is, negative flow in the wet season (from May to September and positive flow in the dry season (from October to April). The flow is adequate even at the average rate of 963 m^3/s, which is equivalent to 83,203,200 m^3/day. The required raw water intake of 165,000 m^3/day (assuming a 10% water treatment loss) corresponding to water demand of Phnom Penh are 150,000 m^3/day (150 MLD), and accounts for only 0.20% of the mean Sap flow.

The required raw water intake to correspond to the future increase in water demand (assuming about +1,000,000 m^3/day with the Sap River as the water source) is at most 1.5% of the annual average flow rate of the Sap River. As well as the Mekong River, it can be expected to give a sufficient quantity for future water source for supply to Phnom Penh Capital.

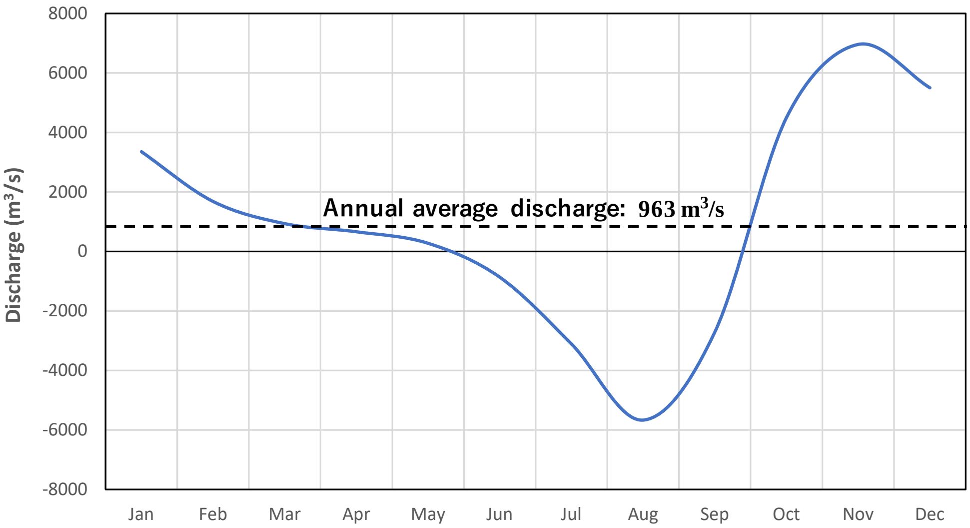


Figure 5.1.22 Sap River Flow Rate at Prek Kdam (Monthly Average of 1996-2020)
Source: JICA Survey Team (2021) based on the data from MOWRAM

3) Water Quality of Sap River

Water quality at Phum Prek was tested as shown in ***Table 5.1.9***.

Table 5.1.9 Water Quality of Sap River at Phum Prek WTP Intake

NO.	PARAMETER	UNIT	RAW WATER QUALITY			NDWQS[*1] (TREATED)
			OVERALL AVE. (RANGE)	DRY SEASON (AVE.)	WET SEASON (AVE.)	
1	Temperature	ºC	28.8 (25.3-31.5)	29.0	28.7	
2	pH	-	7.29 (6.78-7.99)	7.3	7.3	6.5-8.5
3	Turbidity	NTU	106.7 (12-427)	69.2	134.0	<5
4	Conductivity	μs/cm	115.0 (62-258)	120.2	111.2	<1600
5	Suspended Solids (SS)	mg/L	91.6 (10-404)	57.4	116.5	
6	TDS	mg/L	60.6 (31-147)	64.1	58.1	<800
7	Total Coliform	cfu/100ml	19969 (825-366175)	21821	18639	
8	E. Coli	cfu/100ml	6061 (130-108050)	5654	6357	0
9	Ca hardness	mg/L	30.5 (11-66)	29.0	31.6	

NO.	PARAMETER	UNIT	RAW WATER QUALITY			NDWQS[*1] (TREATED)
			OVERALL AVE. (RANGE)	DRY SEASON (AVE.)	WET SEASON (AVE.)	
10	Total Hardness	mg/L	46.1 (23-104)	45.9	46.2	<300
11	Mg hardness	mg/L	16.2 (6-38)	17.6	15.1	
12	Alkalinity	mg/L	41.6 (23-78)	42.4	41.0	
13	Organic substance	mg/L	17.4 (6.32-35.88)	20.2	15.4	
14	DO	mg/L	5.02 (1.76-7.18)	4.43	5.36	
15	Color	mg/L Pt	39.4 (4.53-147.11)	40.6	38.5	<5
16	UV absorption	-	0.20 (0.006-1.023)	0.23	0.17	
17	Aluminum (Al)	mg/L	0.013 (0-0.082)	0.013	0.013	<0.2
18	Ammonia (NH_3)	mg/L	0.52 (0-2.81)	0.59	0.48	
19	NH_4-N	mg/L	0.42 (0-2.3)	0.46	0.40	<1.5
20	Carbon dioxide (CO_2)	mg/L	8.52 (1.5-42)	9.45	7.84	
21	Copper (Cu)	mg/L	0.020 (0-0.1)	0.022	0.019	<1
22	Chloride (Cl^-)	mg/L	24.2 (1-55)	24.5	23.9	<250
23	Cyanide (CN^-)	mg/L	0.003 (0-0.02)	0.003	0.003	<0.07
24	Chromium total (Cr)	mg/L	0.016 (0-0.05)	0.017	0.015	
25	Chromium hexa (Cr^{6+})	mg/L	0.014 (0-0.09)	0.013	0.014	<0.05
26	Fluoride (F^-)	mg/L	0.13 (0-1.14)	0.15	0.11	<1.5
27	Iron (Fe)	mg/L	0.13 (0-1.14)	0.15	0.11	<0.3
28	Manganese (Mn)	mg/L	0.043 (0-0.3)	0.050	0.038	<0.1
29	NO_3-N	mg/L	1.17 (0.33-7.8)	1.21	1.14	
30	Nitrate (NO_3)	mg/L	5.01 (1.5-13.7)	5.33	4.78	<50
31	NO_2-N	mg/L	0.012 (0.002-0.147)	0.016	0.009	
32	Nitrite (NO_2)	mg/L	0.039 (0.0029-0.482)	0.050	0.031	<3
33	Zinc (Zn)	mg/L	0.049 (0-0.28)	0.050	0.048	<3
34	Phosphate (PO_4^{3-})	mg/L	0.21 (0-1.98)	0.25	0.18	
35	Sulphide (S^{2-})	mg/L	0.012 (0-0.098)	0.014	0.011	
36	Sulphate (SO_4^{2-})	mg/L	5.25 (0-32)	5.07	5.38	<250

Source: PPWSA

Raw water at Phum Prek has features as follows:

- High levels of E. Coli detected. This suggests that river water has been polluted by domestic wastewater.
- Dissolved oxygen is low all through a year and organic substances are high in a dry season. This suggests that pollutants are being discharged continuously into the river.
- The low level of chemical contamination indicates that the inflow of industrial wastewater is relatively small.

Time series of main parameter on water quality at Phum Prek intake are shown from ***Figure 5.1.23*** to ***Figure 5.1.28***. Long term monitoring results since 2015 indicate no significant changes in water quality and no major issues as a water source.

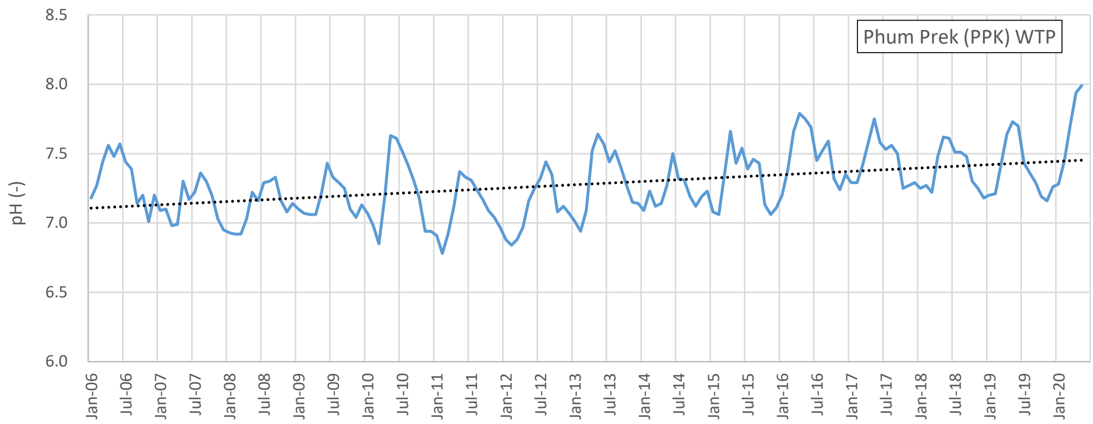


Figure 5.1.23 Long-term Changes of Water Quality at Phum Prek Water Intake (pH)

Source: PPWSA

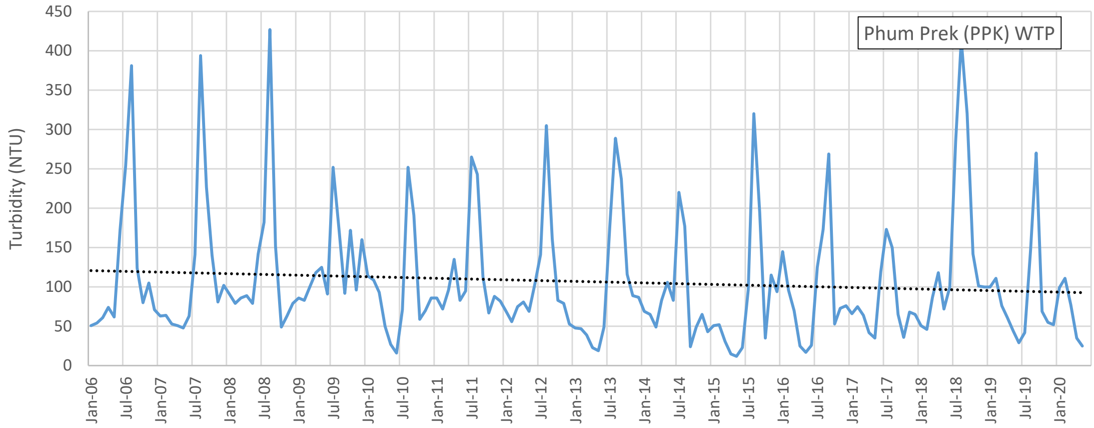


Figure 5.1.24 Long-term Changes of Water Quality at Phum Prek Water Intake (Turbidity)
Source: PPWSA

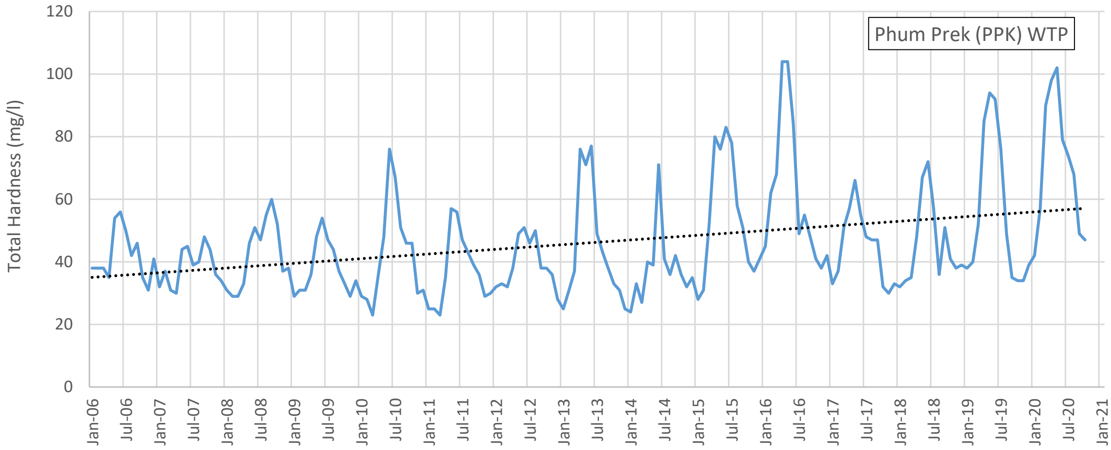


Figure 5.1.25 Long-term Changes of Water Quality at Phum Prek Water Intake (Total hardness)
Source: PPWSA

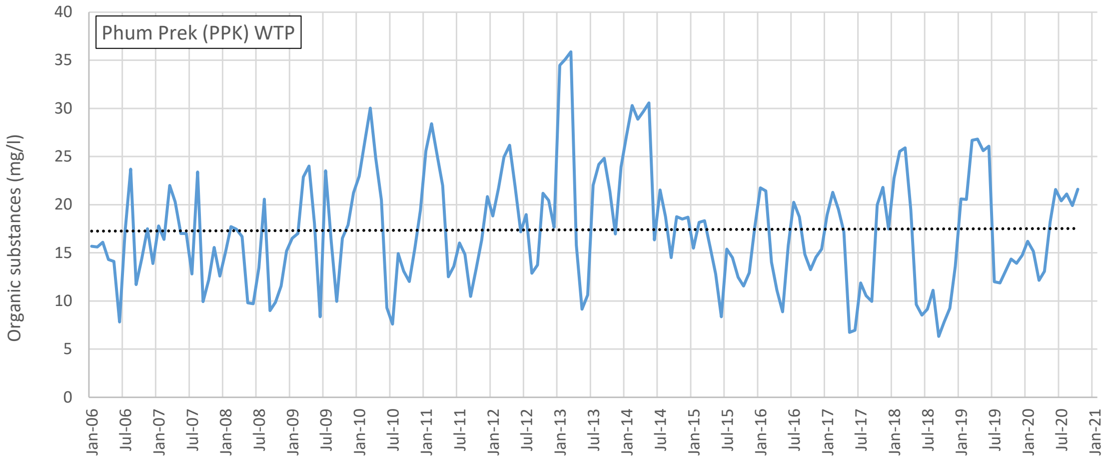


Figure 5.1.26 Long-term Changes of Water Quality at Phum Prek Water Intake (Organic substances)
Source: PPWSA

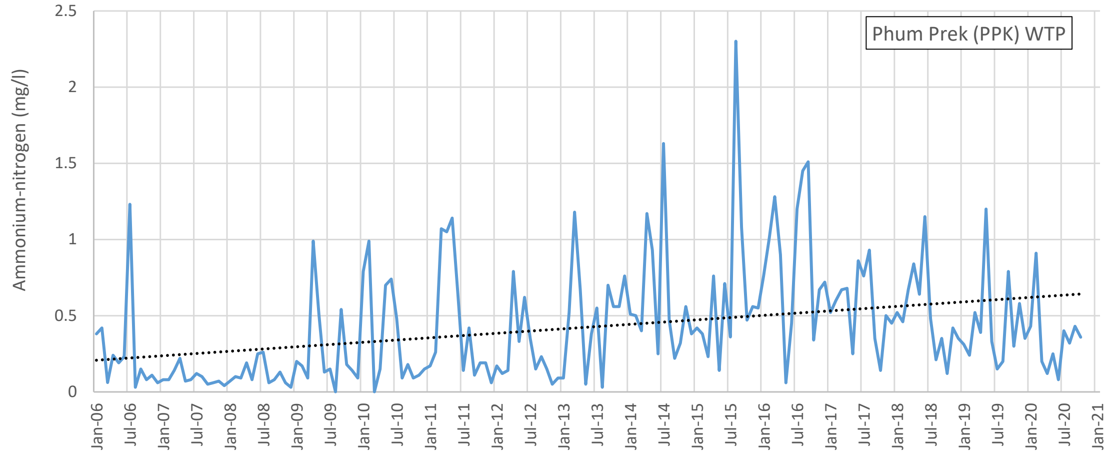


Figure 5.1.27 Long-term Changes of Water Quality at Phum Prek Water Intake (Ammonium-nitrogen)

Source: PPWSA

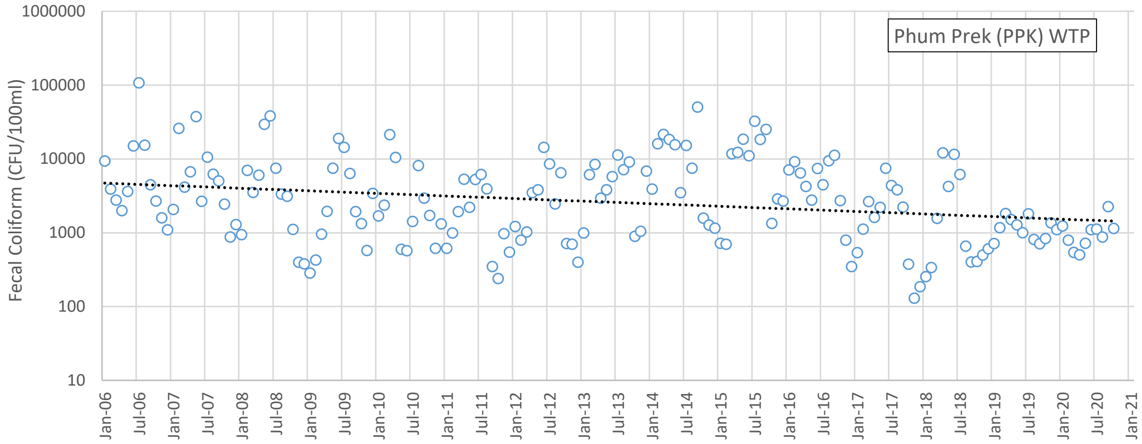


Figure 5.1.28 Long-term Changes of Water Quality at Phum Prek Water Intake (Fecal Coliforms)

Source: PPWSA

This long-term change indicates that there is no significant difference in water quality compared to the current quality. However, total hardness has an increasing trend, and E. Coli has a decreasing trend.

Dissolved oxygen has a strong decreasing trend. ***Table 5.1.10*** summarises these findings:

Table 5.1.10 Trends of Change of Water Quality at Phum Prek WTP

TREND	PARAMETERS
Slight increase / constant	Ammonium, Turbidity, Organic substances, Iron
Increase	Total Hardness
Decrease	Fecal Coliform (E. Coli), Nitrate
Strong decrease	DO

Source: JICA Data Collection Survey Team

(3) Bassac River

1) Water Level of Bassac River

Water level of Bassac River at Chaktomuk is shown in ***Figure 5.1.29***. Water level frequency of Sap River at Chaktomuk is also shown in ***Figure 5.1.30***.

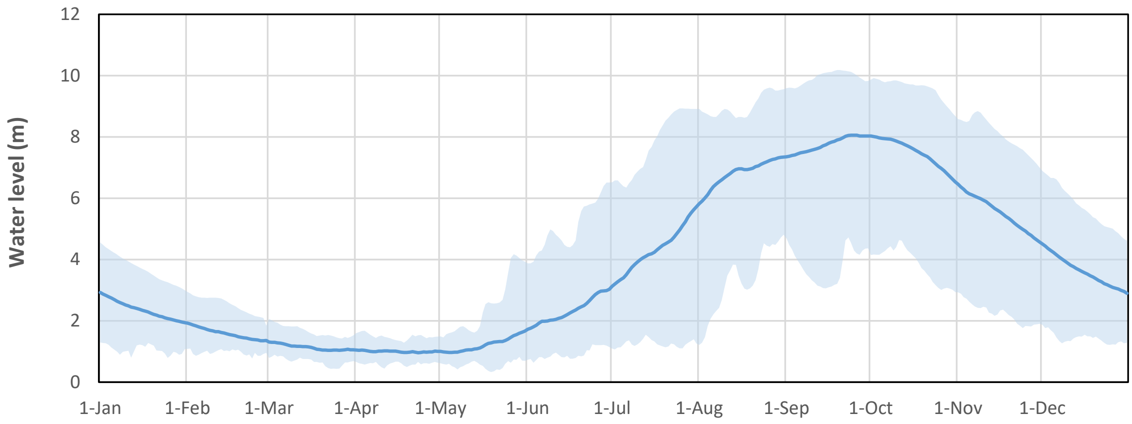


Figure 5.1.29 Bassac River Water Level at Chaktomuk (Daily Average of 1996-2020)
Source: JICA Survey Team (2021) based on the data from DHRW, MOWRAM

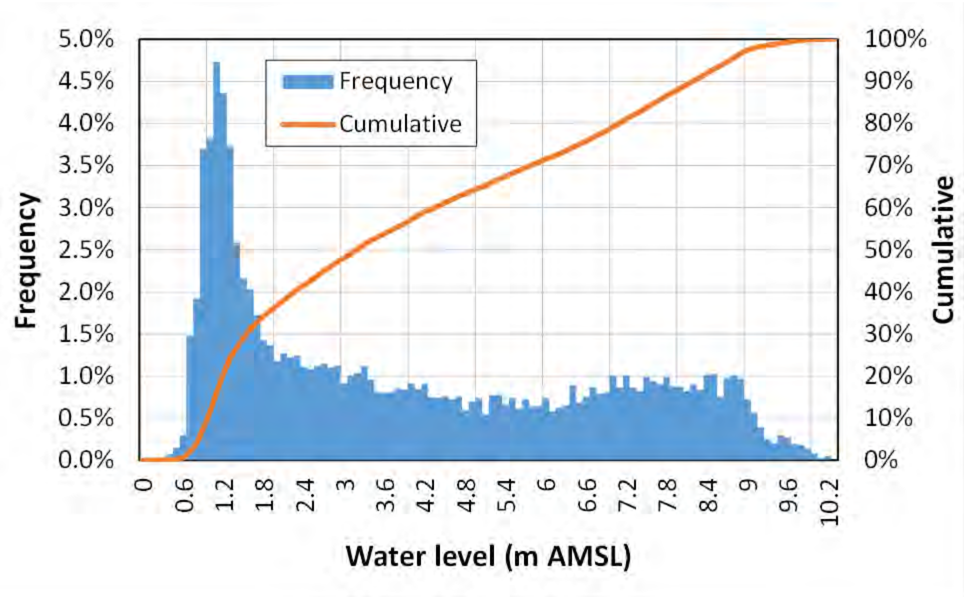


Figure 5.1.30 Water Level Frequency of Bassac River at Chaktomuk
Source: JICA Survey Team (2021) based on the data from DHRW, MOWRAM

Based on these data, average and extreme levels are as follows:

- ✓ Average water level: 3.95 m AMSL
- ✓ Average annual maximum water level: 8.70 m AMSL
- ✓ Average annual minimum water level: 0.86 m AMSL
- ✓ Maximum high water level: 10.18 m AMSL (19/09/2000)
- ✓ Minimum low water level: 0.20 m AMSL (04/05/1960)
- ✓ 99.9% of observed water level is more than 0.40 m AMSL
- ✓ 99% of observed water level is more than 0.64 m AMSL
- ✓ 1 % of observed water level is more than 9.47 m AMSL
- ✓ 0.1 % of observed water level is more than 9.94 m AMSL

2) Flow Rate of Bassac River

The Mekong River connects with the Sap River at Phnom Penh. In the wet season, water from the Mekong flows into the Sap River, and flows upstream to Tonle Sap Lake. The Bassac River is diverted from the Mekong River at a point about 2 km south of the confluence of the Sap River and the Mekong River. Due to the complexity of river formation and flow in the Mekong and Sap Rivers, water composition (water quality and quantity) of the Bassac River has significant seasonal fluctuations. Yearly pattern of river flow around the Chaktomuk river confluence and diversion area is shown in ***Table 5.1.11***. Water composition in

Bassac River based on qualitative approach is as shown in ***Figure 5.1.31*** (values in the graph are for illustration purposes only).

Table 5.1.11 Yearly Pattern of River Flow Observed at Chaktomuk

<table>
<tr><th colspan="2">Early wet season (June-August)</th></tr>
<tr><td>

20/07/2005</td><td>✓ The Mekong flows into the Sap and the Bassac. Therefore, 100% of the Bassac water comes from the Mekong.</td></tr>
<tr><th colspan="2">Tonle Sap inversion (September-November)</th></tr>
<tr><td>

10/11/2014</td><td>✓ The Sap starts to flow into the Mekong, but the velocity is different: high velocity for the Mekong, low velocity for the Sap. That creates a whirl pattern named "Kelvin-Helmholtz instability" which is perfectly visible from planes or satellite pictures.
✓ Therefore, the mixing at Chaktomuk is important, and the water entering the Bassac is a mix of both sources.
✓ Note that the recent extension of Koh Pich increased this phenomenon. It did not really exist before.</td></tr>
<tr><th colspan="2">After wet season (November-February)</th></tr>
<tr><td>

13/02/2015</td><td>✓ The situation is the same as before, but the flow in the Mekong (and therefore velocity) has significantly decreased. Therefore, the whirls disappear, the border line between Sap and Mekong can go quite far to the east and the mixing is less important.
✓ The water in the Bassac is almost entirely made of Sap water during this period.</td></tr>
<tr><th colspan="2">Dry season (February-May)</th></tr>
<tr><td>

12/03/2015</td><td>✓ The Sap flow decreases and becomes close to zero, whereas the Mekong flow remains roughly constant. The influence zone of the Sap, downstream of Chaktomuk, becomes less important.
✓ The Bassac flow is now minimum. It is supposed that some mixing occurs at Chaktomuk, and that the Bassac water is mostly made of Sap water with some Mekong water.</td></tr>
</table>

Source: Rehabilitation and Extension of Chamcar Mon WTP, SAFEGE, (Dec. 2015)

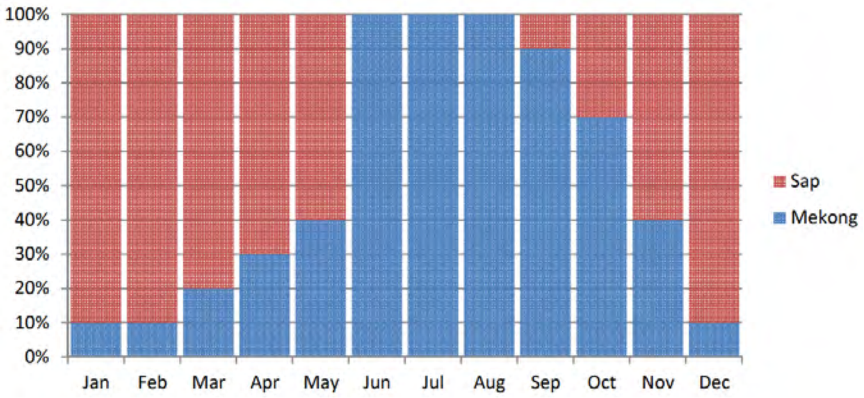


Figure 5.1.31 Empirical Bassac Water Composition
Source: Rehabilitation and Extension of Chamcar Mon WTP, SAFEGE, (Dec. 2015)

Monthly average flow of the Bassac River at Chamcar Mon intake is as shown in ***Figure 5.1.32***. There is significant fluctuation depending on the season. The flow is not sufficient during the dry season. At the minimum rate of 63 m^3/s, which is equivalent to 5,443,200 m^3/day (5,443 MLD), and the required raw water intake of 93,500 m^3/day (assuming a 10% water purification loss) corresponds to the design water treatment capacity of 85,000 m^3/day (85 MLD) at the current and planned WTP using the Bassac River as the water source will account for less than 1.7% of the average annual minimum flow of the Bassac River.

The required raw water intake corresponding to the future increase in water demand (assuming about +100,000 m^3/day with the Bassac River as the water source) is about 3.7% of the average annual minimum flow rate of the Bassac River.

The Phnom Penh Capital is the most upstream part of the Bassac River, and the impact on irrigation water demand in the lower stream area of Kandal Province (mostly pumped water from individual farmers) and water use in Vietnam across national borders should be considered. In a drought year (record monthly average minimum flow rate is 21 m^3/day), the amount of raw water intake may be more than 10% of that flow rate. Although the flow rate at the water intake point is not insufficient, from the viewpoint of securing the maintenance flow and irrigation water intake in downstream areas, careful consideration is required to prevent excessive water intake. Therefore, unlike the Mekong and Sap rivers, it is difficult to develop a large-scale water intake of hundreds of thousands of m^3 per day on the Bassac river.

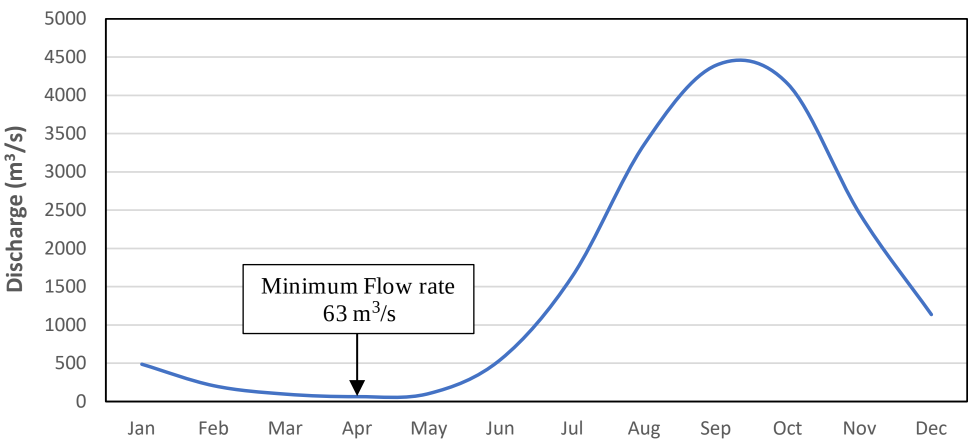


Figure 5.1.32 Bassac River Flow Rate at Chamcar Mon station (Monthly Average of 1960-2014)
Source: JICA Survey Team (2021) based on the data from DHRW, MOWRAM

3) Water Quality of Bassac River

Water quality at Chamcar Mon was tested as shown in ***Table 5.1.12***. There were no significant water quality issues.

Table 5.1.12 Water Quality of Bassac River at Chamcar Mon WTP Intake

NO.	PARAMETER	UNIT	RAW WATER QUALITY (RANGE)			NDWQS*1 (TREATED)
			OVERALL AVE. (RANGE)	DRY SEASON (AVE.)	WET SEASON (AVE.)	
1	Temperature	ºC	28.5 (25.2-31.2)	28.6	28.4	
2	pH	-	7.44 (6.88-8.11)	7.5	7.4	6.5-8.5
3	Turbidity	NTU	135.6 (8-799)	55.1	197.1	<5
4	Conductivity	µs/cm	134.5 (72-259)	153.2	120.1	<1600
5	Suspended Solids (SS)	mg/L	101.8 (6-532)	40.3	148.8	
6	TDS	mg/L	67.5 (36-130)	76.7	60.5	<800
7	Total Coliform	cfu/100ml	13766 (400-458100)	10430	16317	
8	E. Coli	cfu/100ml	875 (36-11867)	882	870	0
9	Ca hardness	mg/L	35.5 (12-70)	38.5	33.3	
10	Total Hardness	mg/L	52.1 (24-116)	57.9	47.6	<300
11	Mg hardness	mg/L	16.9 (4-46)	19.6	14.9	
12	Alkalinity	mg/L	45.5 (24-79)	50.4	41.8	
13	Organic substance	mg/L	13.8 (2.9-30.39)	13.5	14.1	
14	DO	mg/L	7.23 (6.18-8.5)	7.18	7.28	
15	Color	mg/L Pt	35.7 (4.91-182)	31.7	38.7	<5
16	UV absorption	-	0.17 (0.007-1.134)	0.15	0.19	
17	Aluminum (Al)	mg/L	0.01 (0-0.11)	0.011	0.011	<0.2
18	Ammonia (NH_3)	mg/L	0.28 (0-1.81)	0.22	0.31	
19	NH_4-N	mg/L	0.22 (0-1.48)	0.18	0.25	<1.5
20	Carbon dioxide (CO_2)	mg/L	6.01 (1-21)	6.44	5.68	
21	Copper (Cu)	mg/L	0.02 (0-0.11)	0.019	0.021	<1
22	Chloride (Cl^-)	mg/L	22.0 (7.4-50)	22.4	21.8	<250
23	Cyanide (CN^-)	mg/L	0.003 (0-0.03)	0.002	0.003	<0.07
24	Chromium total (Cr)	mg/L	0.013 (0-0.03)	0.014	0.013	
25	Chromium hexa (Cr^{6+})	mg/L	0.010 (0-0.03)	0.010	0.009	<0.05
26	Fluoride (F^-)	mg/L	0.14 (0-0.48)	0.14	0.13	<1.5
27	Iron (Fe)	mg/L	0.49 (0-6.88)	0.30	0.64	<0.3
28	Manganese (Mn)	mg/L	0.036 (0-0.23)	0.035	0.037	<0.1
29	NO_3-N	mg/L	1.06 (0-3.54)	1.09	1.04	
30	Nitrate (NO_3)	mg/L	4.56 (0-11.49)	4.60	4.53	<50
31	NO_2-N	mg/L	0.008 (0-0.09)	0.009	0.008	
32	Nitrite (NO_2)	mg/L	0.027 (0-0.164)	0.033	0.022	<3
33	Zinc (Zn)	mg/L	0.038 (0-0.17)	0.036	0.040	<3
34	Phosphate (PO_4^{3-})	mg/L	0.19 (0.01-1.5)	0.19	0.19	
35	Sulphide (S^{2-})	mg/L	0.013 (0-0.33)	0.014	0.012	
36	Sulphate (SO_4^{2-})	mg/L	7.39 (0-34)	9.13	6.06	<250

Source: PPWSA

Raw water at Chamcar Mon has features as follows:

- Dissolved oxygen stays higher than other rivers.
- E. Coli is relatively low, but total coliforms are high. Contamination by domestic wastewater is relatively small, and it is considered that the water quality is rich in bacteria for other reasons.
- Turbidity is high in wet season. Since the Bassac flow in the wet season is dominated by the inflow from the Mekong River, it is considered to have similar characteristics.
- Chemical contamination levels are low.

Time series of main parameter on water quality at Chamcar Mon intake are shown from ***Figure 5.1.33*** to ***Figure 5.1.38***. Long term monitoring results since 2015 indicate no significant changes in water quality and no major issues as a water source.

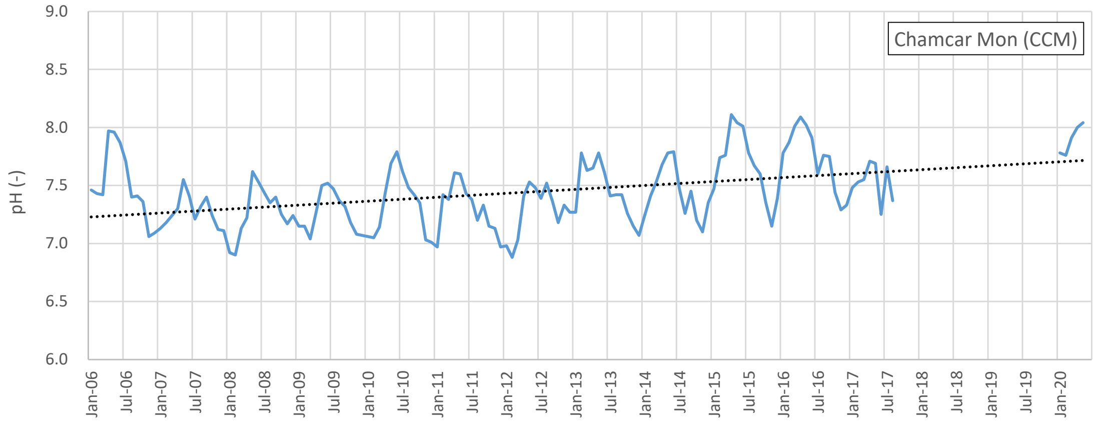


Figure 5.1.33 Long-term Changes of Water Quality at Chamcar Mon Water Intake (pH)
Source: PPWSA

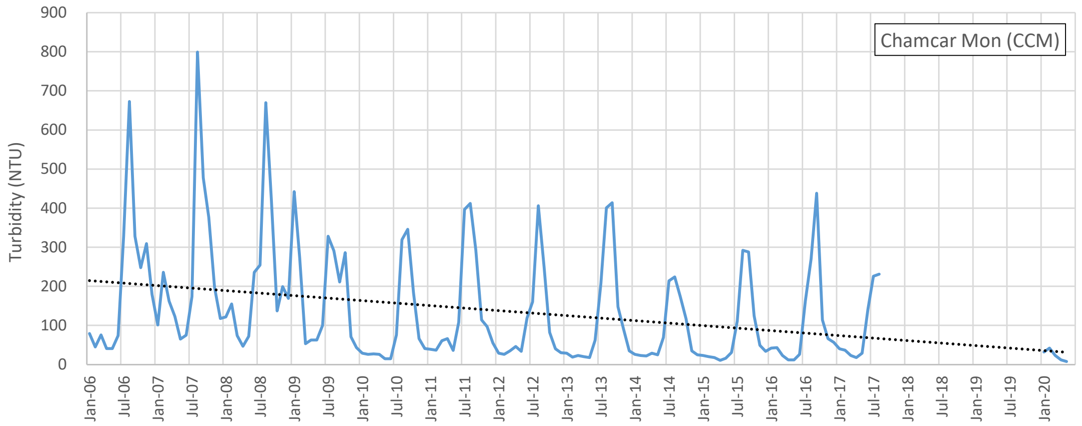


Figure 5.1.34 Long-term Changes of Water Quality at Chamcar Mon Water Intake (Turbidity)
Source: PPWSA

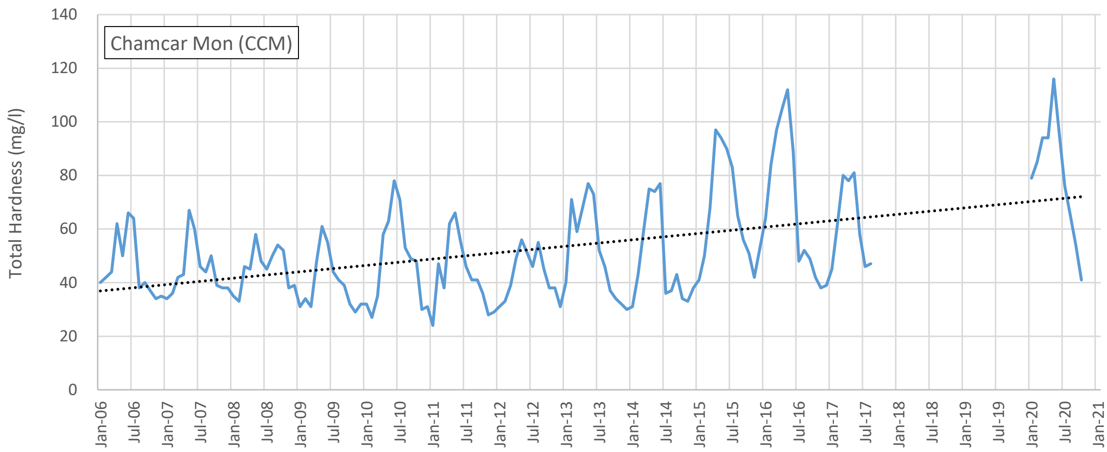


Figure 5.1.35 Long-term Changes of Water Quality at Chamcar Mon Water Intake (Total hardness)
Source: PPWSA

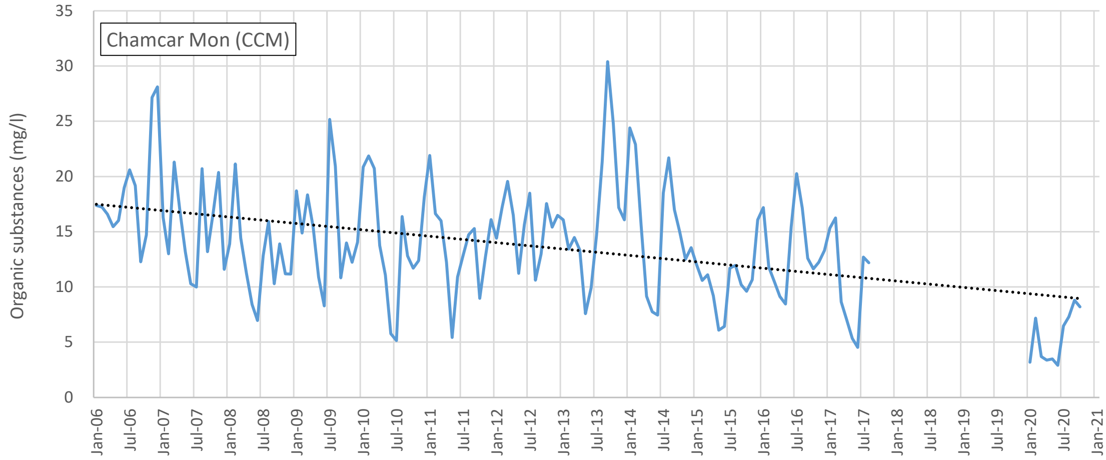


Figure 5.1.36 Long-term Changes of Water Quality at Chamcar Mon Water Intake (Organic substances)

Source: PPWSA

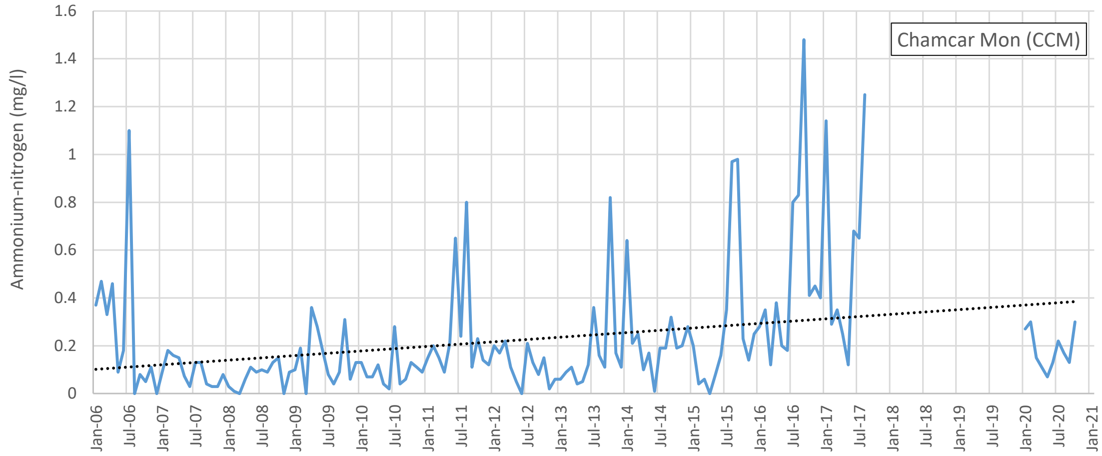


Figure 5.1.37 Long-term Changes of Water Quality at Chamcar Mon Water Intake (Ammonium-nitrogen)

Source: PPWSA

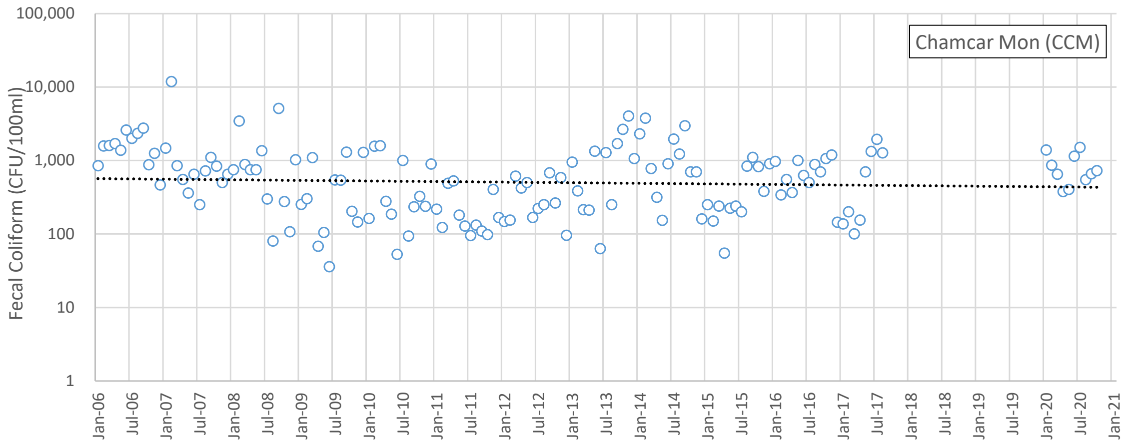


Figure 5.1.38 Long-term Changes of Water Quality at Chamcar Mon Water Intake (Fecal Coliforms)

Source: PPWSA

This long-term change indicates that there is no significant difference in water quality compared to current conditions. However, organic substances have strong decreasing trend, and ammonia and total hardness have an increasing trend. ***Table 5.1.13*** summarises these findings:

Table 5.1.13 Trends of Change of Water Quality at Chamcar Mon WTP

TREND	PARAMETERS
Slight increase / constant	Turbidity, Fecal Coliform (E. Coli), DO, Iron
Increase	Ammonium, Total Hardness
Decrease	Nitrate
Strong decrease	Organic substances

Source: JICA Data Collection Survey Team

(4) Prek Thnot River

1) Water Level of Prek Thnot River

Average daily water level of Prek Thnot River at Peam Khley station is shown in ***Figure 5.1.39.*** Frequency of water level are also shown in ***Figure 5.1.40***.

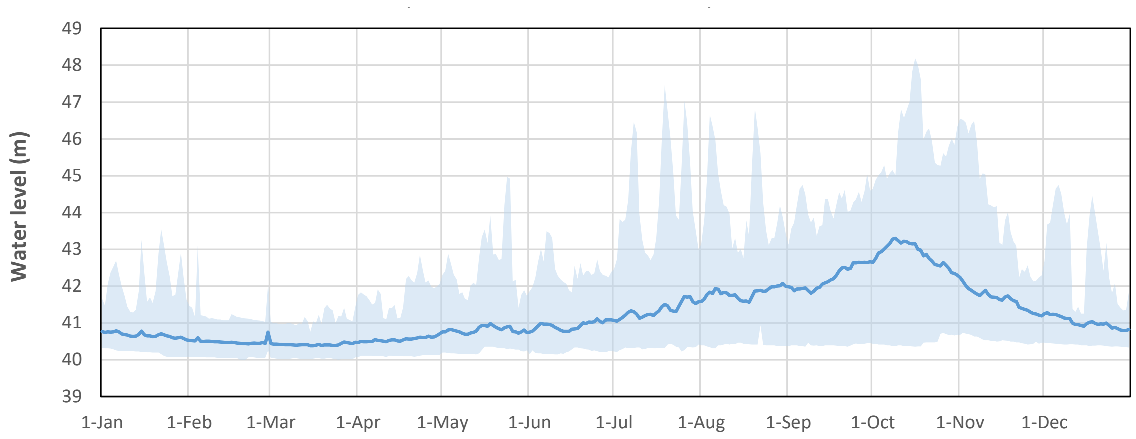


Figure 5.1.39 Prek Thnot River Water Level at Peam Khley (Daily Average of 1996-2020)
Source: JICA Survey Team (2021) based on the data from Kampong Spue DOWRAM

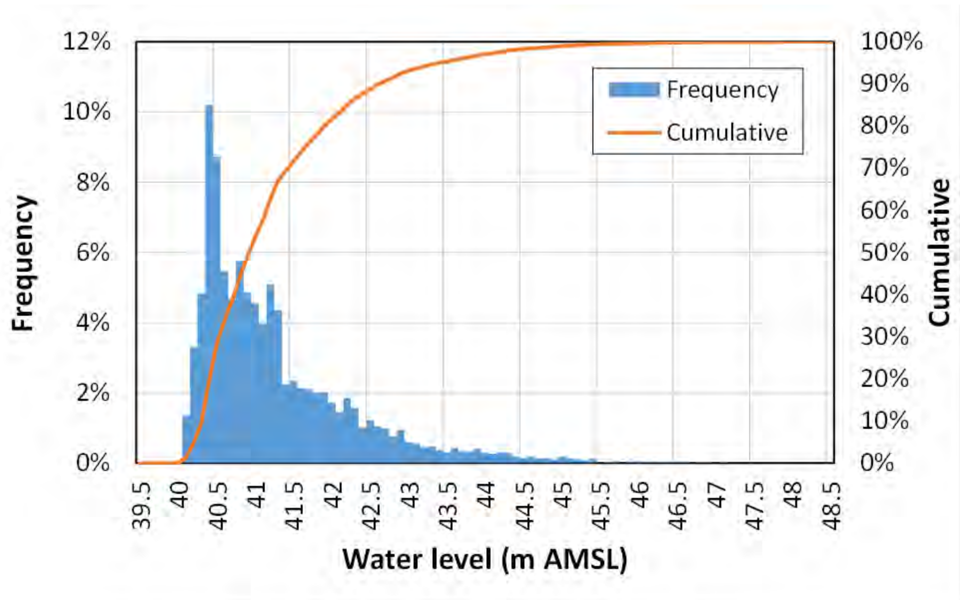


Figure 5.1.40 Water Level Frequency of Prek Thnot River at Peam Khley
Source: JICA Survey Team (2021) based on the data from Kampong Spue DOWRAM

Based on these data, average and extreme levels are as follows:

- ✓ Average water level: 41.23 m AMSL
- ✓ Average annual maximum water level: 45.27 m AMSL
- ✓ Average annual minimum water level: 40.23 m AMSL
- ✓ Maximum high water level: 48.19 m AMSL (16/10/2000)

- ✓ Minimum low water level: 40.00 m AMSL (19/02/2010)
- ✓ 99.9% of observed water level is more than 40.01 m AMSL
- ✓ 99% of observed water level is more than 40.09 m AMSL
- ✓ 1 % of observed water level is more than 45.09 m AMSL
- ✓ 0.1 % of observed water level is more than 46.79 m AMSL

2) Flow Rate of Prek Thnot River

Monthly average flow of the Prek Thnot River at Peam Khley is shown in ***Figure 5.1.41***. The flow shows a significant variability between the dry and wet seasons. The flow is very small compared to the other rivers throughout the year. A water balance between available river flow and the current water users' requirements (***Table 5.1.14***) shows a shortage of water in the dry season (January, February, and April).

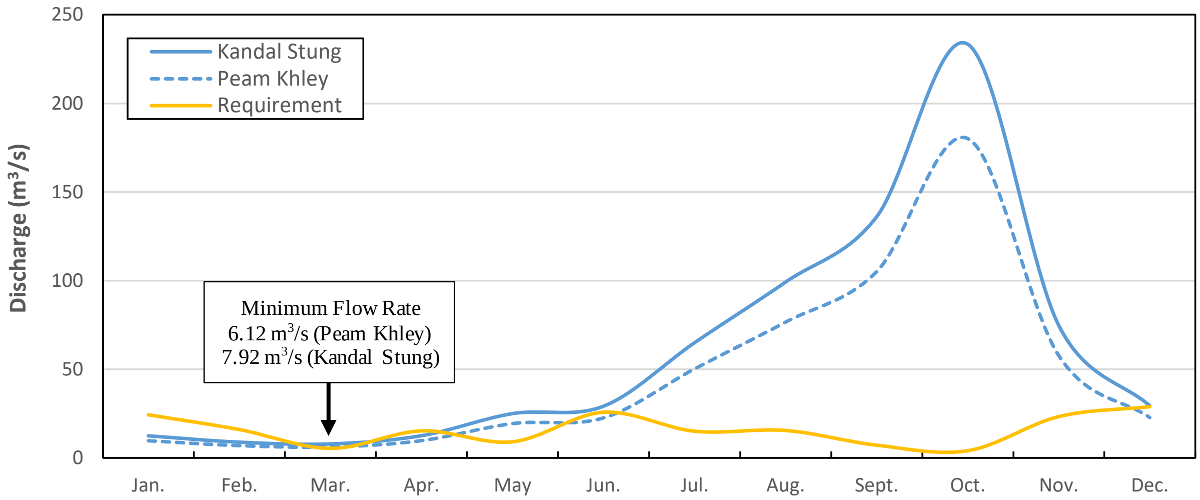


Figure 5.1.41 Prek Thnot River Flow Rate at Peam Khley
Source: JICA Survey Team (2021) based on the data from Kampong Spue DOWRAM

Table 5.1.14 Water Balance of the Prek Thnot River

(m^3/s)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Prek Thnot River Flow												
At Peam Khley	9.65	6.89	6.12	9.71	19.3	22.5	50.2	76.6	105.0	180.2	57.7	22.7
At Kandal Stung*	12.50	8.93	7.92	12.58	25.0	29.2	65.0	99.2	136.1	233.4	74.8	29.5
Requirement												
Roleang Chrey zone 1	0.00	0.00	0.00	11.0	6.38	4.53	3.39	4.30	2.58	0.61	5.19	5.06
Roleang Chery zone 2	21.1	15.1	4.79	0.00	0.00	15.8	8.11	7.43	2.44	2.56	14.4	18.7
Kandal Stung	0.00	0.00	0.00	3.69	2.14	1.52	1.14	1.44	0.87	0.20	1.74	1.70
Tonle Bati	2.69	0.36	0.00	0.00	0.00	3.33	1.84	1.71	0.71	0.11	1.38	2.86
PPSEZ	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087
River Maintenance flow	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Total Requirement	24.5	16.1	5.5	15.4	9.2	25.9	15.2	15.6	7.3	4.2	23.4	29.0
Water Balance	-12.0	-7.2	2.4	-2.8	15.8	3.3	49.9	83.7	128.8	229.2	51.4	0.4

*: Using the ratio of the basin area to the Peam Khley point, the flow rate was calculated as increasing proportionally.
Source: JICA Survey Team (2021) based on the data from MOWRAM

3) Water Quality of Stung Prek Thnot River

Water quality of Stung Prek Thnot River was not described in the Third Master Plan since it was difficult to ensure enough water in the downstream area and discussion and evaluation mainly focused on supply capacity from existing and planned dams in the upstream area. There are no available water quality data in the Prek Thnot River except at the downmost stream. Some limited parameters have been monitored at Ta Khmao Bridge in the downmost stream of the Prek Thnot River by MOE, as shown ***Table 5.1.15***. In the following section (see ***Section 5.2.1***), water quality survey results implemented in this study will be shown as an information for evaluating the location of new water source.

Table 5.1.15 Water Quality of Prek Thnaot River at Ta Khmao Bridge (Stung Chrov)

NO.	PARAMETER	UNIT	RAW WATER QUALITY (RANGE)			STANDARD (NDWQS, TREATED)
			OVERALL AVE. (RANGE)	DRY SEASON (AVE.)	WET SEASON (AVE.)	
1	pH	-	7.32 (6.51-8.38)	7.34	7.34	6.5-8.5
2	Suspended Solids (SS)	mg/L	118.3 (60-246)	123.0	98.79	<800
3	BOD	mg/L	26.97 (1.00-69.00)	26.54	14.45	(<10) *
4	COD_{cr}	mg/L	57.85 (8.00-124.16)	56.06	31.06	
5	Total Nitrogen (TN)	mg/L	4.10 (0.18-8.69)	4.86	2.27	(<100) *
6	Total Phosphorus (TP)	mg/L	0.76 (0.08-2.40)	1.71	0.65	
7	Chromium (Cr)	mg/L	0.0073 (ND-0.04)	0.018	0.014	<0.05

*: Environmental standards on river water
Source: MOE, 2010-2019

(5) Stored Water of Dams

As one water source option, the availability of water from the dams and reservoirs located in the Prek Thnot River basin adjacent to Phnom Penh is described.

1) Rainfall Characteristics of the Prek Thnot River Basin

Figure 5.1.43 shows the long-term tendency of annual rainfall in Phnom Penh. There is almost no change in that tendency, and it can be seen that it has not been significantly affected by climate change. On the other hand, according to ***Table 5.1.16***, the Prek Thnot River basin has relatively less precipitation than the surrounding area (annual precipitation of about 1,100 to 1,250 mm). It is an area where a stable supply of water is required in the dry season due to dam construction and reservoir management from the viewpoint of securing water sources.

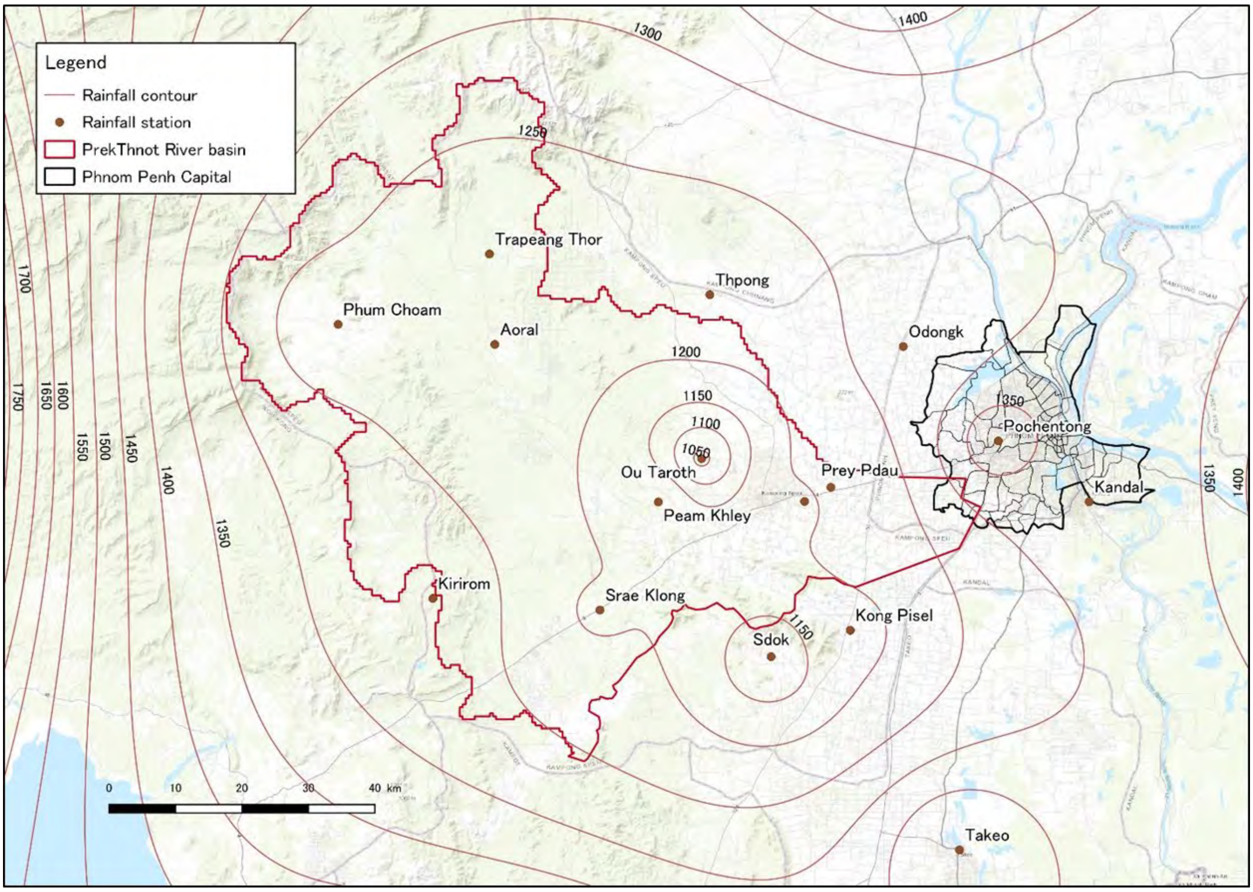


Figure 5.1.42 Precipitation station location and iso-rainfall diagram around the Prek Thnot river basin (annual rainfall)

Source: JICA Survey Team (2021) based on the data from MOWRAM

Table 5.1.16 Precipitation at Pochentong Observatory (Phnom Penh) (1901-2020)

(mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average	7.6	7.5	27.2	72.6	138.9	148.0	151.4	167.7	243.2	254.9	125.9	35.1	1380.0
Ratio	1%	1%	2%	5%	10%	11%	11%	12%	18%	19%	9%	3%	100%
Max	83.8	127.4	211.5	359.2	395.1	392.8	358.9	379.9	474.3	649.7	345.8	301.1	2309.7
Min	0.0	0.0	0.0	0.0	24.6	26.9	37.3	44.4	93.2	62.7	1.6	0.0	934.7

Source: MOWRAM (data of 1990-2020), Australian Catholic Relief in December 1991 (data of 1901-1989)

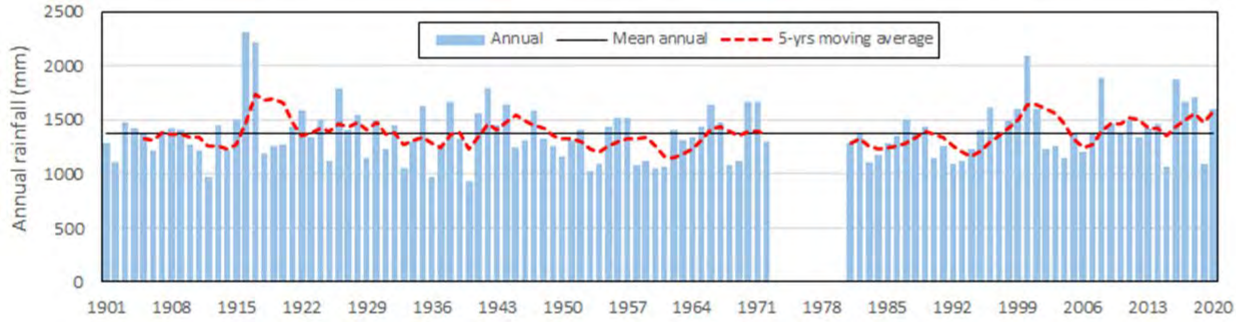


Figure 5.1.43 Long-term fluctuations in annual precipitation at Phnomentong Observatory (1901-2020)

*Missing data from 1973 to 1980
Source: JICA Survey Team (2021) based on the data from MOWRAM

Table 5.1.17 Rainfall Station around the Prek Thnot River Basin

No.	STATION	X UTM48N (m)	Y UTM48N (m)	MEAN ANNUAL RAINFALL (mm)	5-YERAS DRY RAINFALL (mm)	OBSERVATION PERIOD
1	Pochentong	481827	1276800	1380.0	1170.0	1901-1972, 1981-2020
2	Kampong Spue	452737	1267615	1185.3	970.8	1966-1969, 1983-2020
3	Aoral	406283	1291636	1209.4	1044.5	1997-2020
4	Kong Pisely	459565	1248004	1137.3	948.4	1983-2020
5	Thpong	438559	1299115	1221.8	1009.1	1987-2020
6	Phnom Sroech	432151	1258216	1124.0	888.1	1983-2020
7	Udong	467570	1291192	1260.9	1073.6	1987-2003, 2005-2020
8	Peam Khley	430769	1267572	1189.2	939.7	2000-2020
9	Roleang Chrey	439465	1265187	1243.3	1125.1	2016-2020
10	Ou Tharot	437266	1274160	1043.1	768.9	2000-2020
11	Kirirom	396851	1252984	1462.6	1126.5	2000-2005, 2018-2020
12	Srae Klong	421952	1251144	1196.0	943.8	2000-2009, 2011-2020
13	Sdok	447664	1244004	1099.5	750.8	2000-2020
14	Trapeang Chor	405516	1305409	1201.2	994.3	2000-2020
15	Phum Choam	382775	1294755	1223.8	995.6	2017-2020
16	Prey Phdau	456680	1269772	1234.2	1043.2	1997-2018

2) Existing and Planned Dams and Water Storage Facilities

In the upper stream of the Prek Thnot River basin, several existing dams and water storage facilities are operated mainly for the purpose of supplying irrigation water and partly for flood management (managed by Kampong Spue Province DOWRAM). In addition, although there are dam construction plans by international donors, the projects have not yet been implemented. According to MOWRAM, the water supply to the planned irrigation area is also insufficient, so it is very difficult to supply water to the reservoir outside the irrigation project in the short to medium term. ***Figure 5.1.44*** shows the layout of dams existing or planned in the Prek Thnot River basin and adjacent areas. The characteristics of existing and planned dams in the basin are summarized in ***Table 5.1.18***.

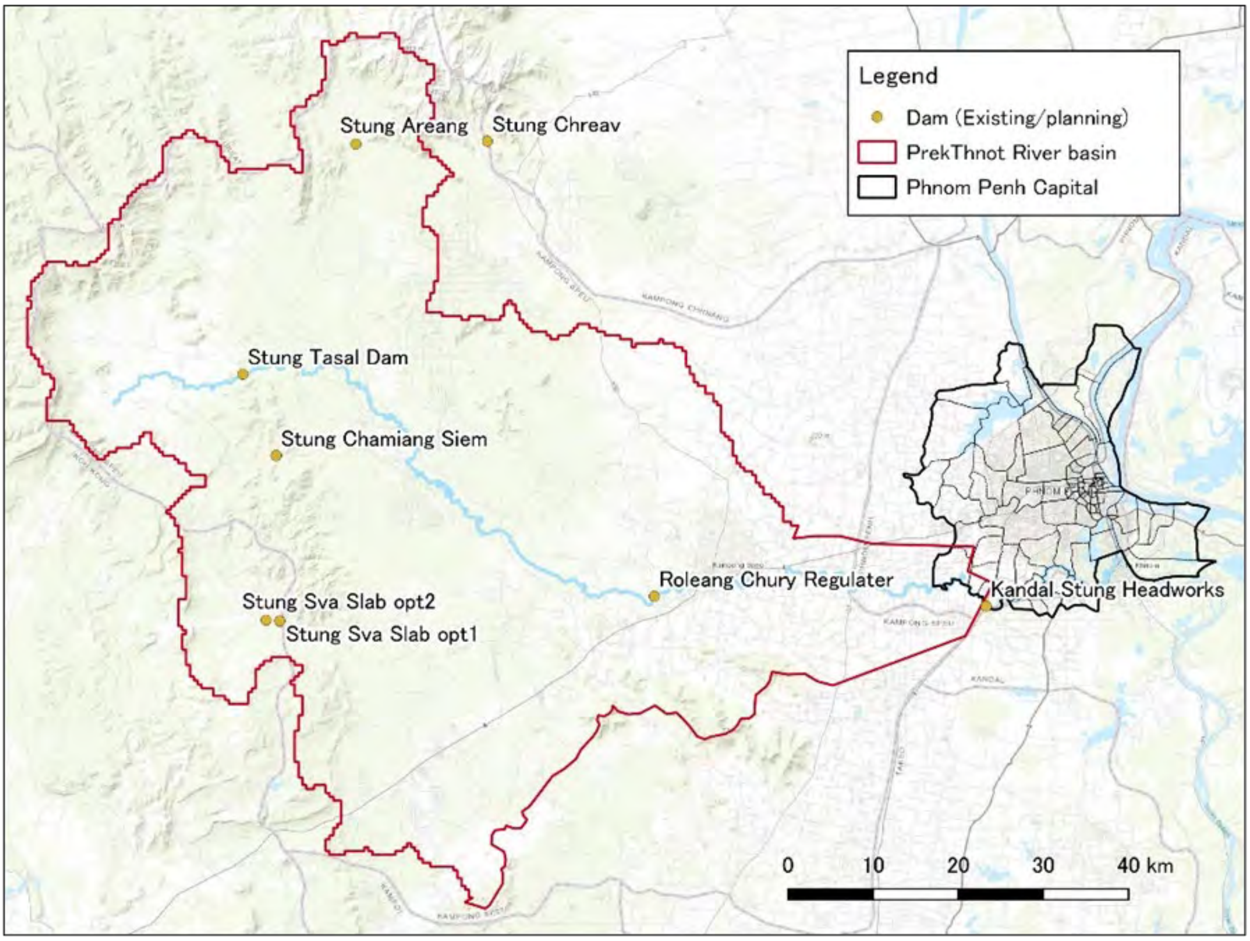


Figure 5.1.44 Location Map of Existing and Planned Dams in the Prek Thnot River Basin

Source: Created by JICA Survey Team (2021) based on the data from MOWRAM

Table 5.1.18 Status of Existing and Planned Dams and Water Storage Facilities in the Prek Thnot River Basin

NO.	DAM	RIVER	PURPOSE	STORAGE VOLUME (MCM)	PROGRESS OF CONSTRUCTION/PLAN
1	Tasal Dam	Prek Thnot	Irrigation, flood control	1.35 (Irrigated area: 6,800 ha)	Existing (There was a Phase 2 plan to build a headworks downstream of the dam, but it was canceled.)
2	Peam leaver Dam	Aveang	Irrigation	8	Existing (with renovation plan)
3	O Tang Dam	Ou Khlong	Irrigation	6	Existing (with renovation plan)
4	Sva Slab Dam	Sva Slab	Irrigation	124	Plan (Indian government, undeveloped but scheduled to start project in 2023)
5	Stung Aveang Dam	Aveang	Irrigation	100	Plan (Korean government proposed, not yet started)
6	Southern Reservoir	Ou Kbong	Hydropower	Unknown	Existing (only the dam needs to raise the water storage level, but it is difficult because farmers live illegally.)
7	Anluong Khley Reservoir	Anluong Khley	Irrigation	Unknown	Existing (renovated in 2013)

Source: Created by JICA Survey Team (2021) based on the data from MOWRAM

In addition, the conditions for using these dams as water sources for Phnom Penh Capital are shown. Since these conditions are not of a nature that can be met in the short term, PPWSA will consider continuous and systematic measures from the perspective of long-term water supply business operation. It is positioned as a preparation for further expansion of water demand and water supply in the future.

✓ Consultation with the Ministry of Water Resources and Meteorology, which has jurisdiction over dams and reservoirs, to obtain water allocation

- ✓ Establishment of committee or any other stakeholders meeting for discussions and coordination among other water users
- ✓ Securing a waterway from the dam reservoir to a WTP in the western part of Phnom Penh or its suburbs (use of natural rivers or construction of aqueducts)
- ✓ Feasibility study of water conveyance based on the distance and elevation difference between the dam site and the candidate site for the WTP

(6) Groundwater

As concluded in the previous master plans, there is no potential for groundwater to meet the large-scale water supply needs of Phnom Penh Capital. In addition to the quantitative aspect, there is also a qualitative risk of high iron and arsenic concentrations as described below. Therefore, the possibility of groundwater serving as a significant urban water source is low. ***Table 5.1.19***, ***Figure 5.1.45*** and ***Figure 5.1.46*** show the status of exceeding the water quality standard values of iron and arsenic in the wells around Phnom Penh and the distribution of contaminated wells, respectively. Pollution by both substances is of natural origin, the flow velocity of groundwater is small, and considering the characteristics of groundwater quality that is strongly influenced by geology. These are based on the results of surveys before 2010. However, no major changes have been observed

In Cambodia, water quality standards that are specific to groundwater quality have not been set. However, standards equivalent to those for drinking water quality are applied. On the other hand, since groundwater is generally of better quality than surface water, it is promising as a water source for relatively small-scale water supply. It may be used if it is positioned as a small-scale supplementary water source in areas far from WTPs in the present and future, rather than meeting the large water demand in Phnom Penh.

Table 5.1.19 Pollution of Wells around the Capital Phnom Penh by Iron and Arsenic

POLLUTANT	NO. OF DETECTECD WELLS	TOTAL NO. OF WELLS	STANDARD CONCENTRATION	EXCEEDING RATE	REMARKS
Arsenic	11,427	42,858	50 μg/l	26.7 %	- Including wells in the area around Phnom Penh - The standard value is for drinking water
Iron	6,064	42,858	0.3 mg/l	14.1 %	

Source: Created by JICA Survey Team (2021) based on the data from World Bank (2010) (https://cambodiawellmap.com/worldbank/maps)

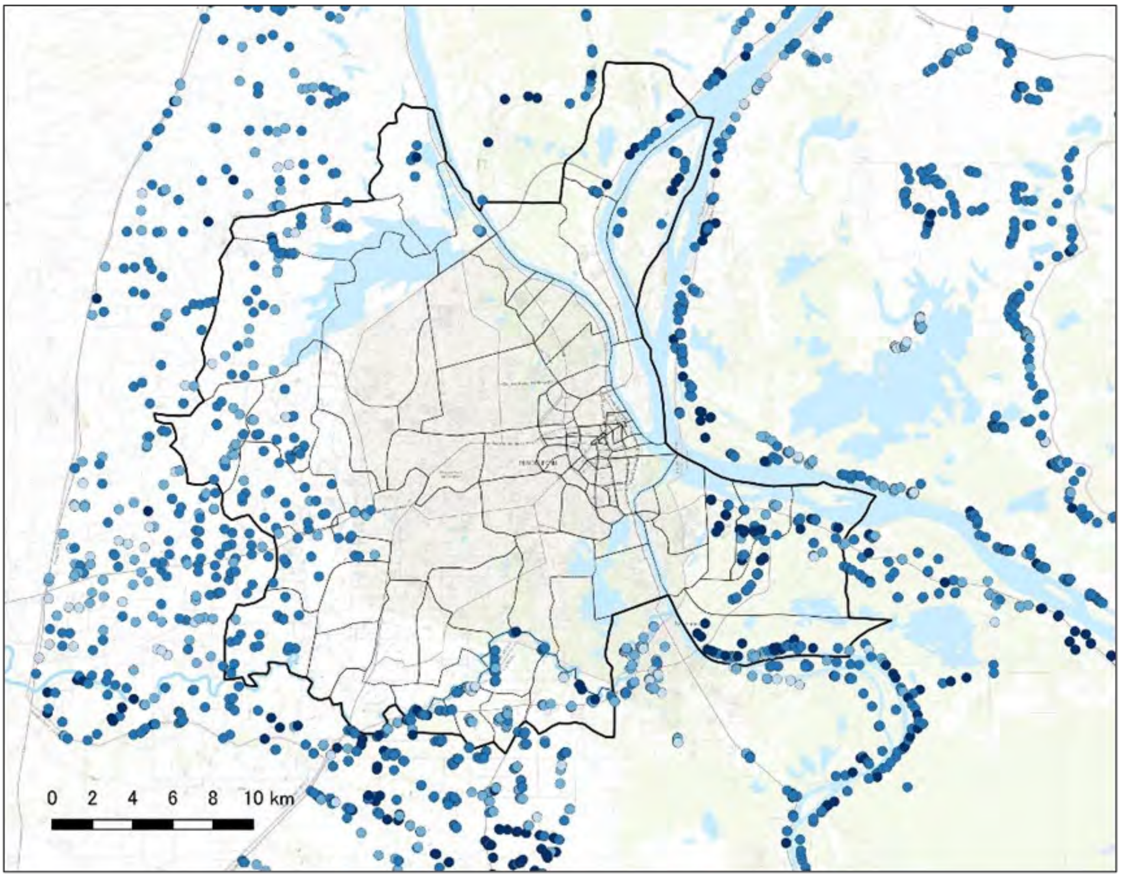


Figure 5.1.45 Distribution of Wells with High Iron Concentration
Source: Created by JICA Survey Team (2021) based on the data from World Bank (2010)

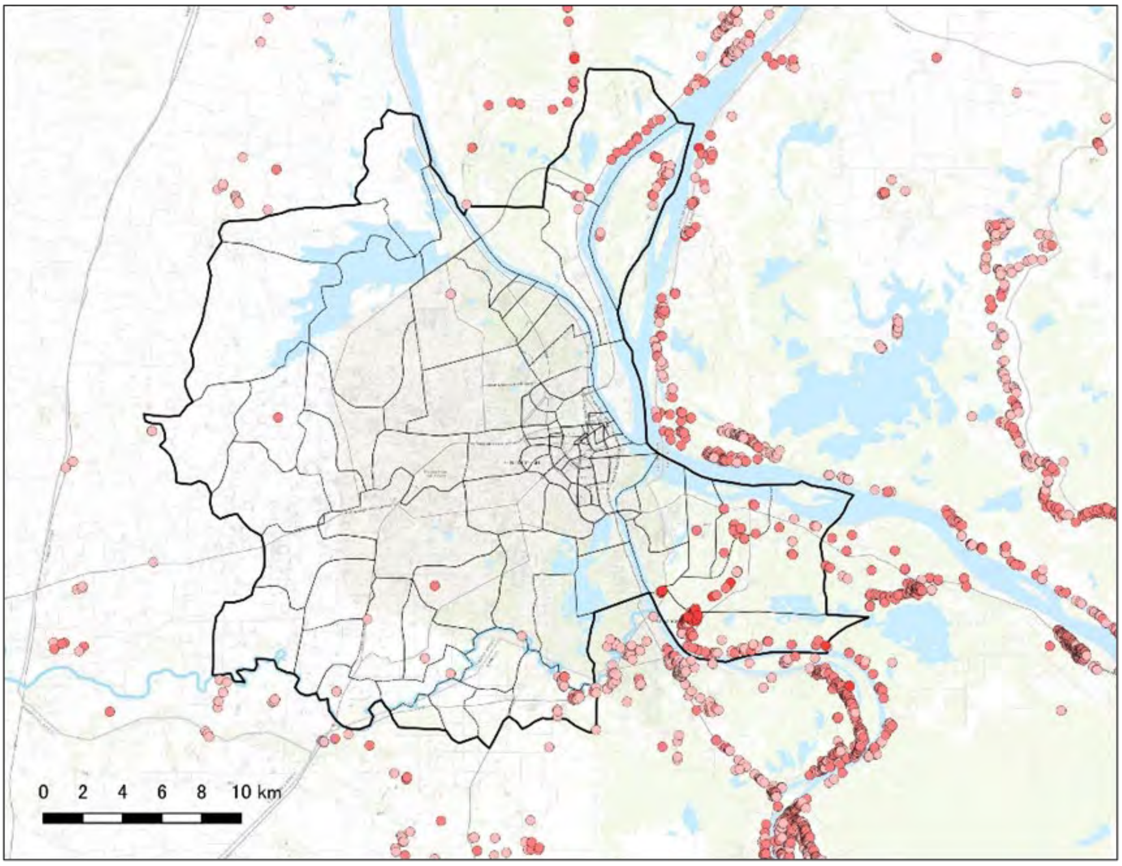


Figure 5.1.46 Distribution of Wells with High Arsenic Concentration
Source: Created by JICA Survey Team (2021) based on the data from World Bank (2010)

5.1.3 Summary and Primary Evaluation Result of Water Resource Options

Table 5.1.20 summarizes the results of the primary evaluation of potential water sources descripted in the above sections. The evaluation revealed that candidate rivers have the potential to meet required intake volumes, although there is some difference in the scale of the raw water intakes. On the other hand, groundwater and dams / reservoirs show little or no possibility of development due to numerous obstacles and issues as water sources and to meet the 2030 water demand.

Table 5.1.20 Result of Primary Evaluation to Candidate Water Resources

NO.	CANDIDATE WATER SOURCE	FLOW RATE	WATER LEVEL	WATER QUALITY
1	Mekong River	Sufficient amount throughout the year, no impact on upstream and downstream	There is a difference in maximum and minimum water levels of about 10 m.	There are no particular problems.
2	Sap River	Sufficient amount throughout the year, no impact on upstream and downstream	There is a difference in the maximum and minimum water levels of about 8 m.	Nitrogen concentration and E. coli tend to be relatively high, but the level that can be handled by water treatment.
3	Bassac River	Sufficient, but in the dry season, water intake may affect downstream water use and environment.	There is a difference in maximum and minimum water levels of about 8 m.	Nitrogen concentration, E. coli, and hardness tend to be relatively high, but water treatment can be used.
4	Prek Thnot River	Insufficient in the dry season, priority is given to irrigation water demand	There is a difference in the maximum and minimum water levels of about 5 m.	Due to lack of data, the tendency of water quality in the target area is unknown.
5	Groundwater	A large number of wells are required to meet water demand, and the management burden is large.	There are no problems such as abnormal reduction of groundwater levels.	There are many wells which the iron and arsenic concentrations exceed the standards.
6	Dam and Reservoir	Almost occupied by the allocation to irrigation water, long-term efforts are required to secure the allocation amount for other uses, and long-distance water conveyance is required.	No specific information	No water quality problems have been confirmed in existing dams.

Source: JICA Survey Team (2021)

5.2 EVALUATION AND CHOICE OF WATER RESOURCE

5.2.1 Candidate Water Source for New Water Intake Facility

Considering the current status and characteristics of each water source, future water demand (quantity and demand area), expansion of existing facilities of WTPs, and location potential of new facilities, the candidates for water sources (intake locations) to meet future demand were investigated for four rivers, excluding groundwater and dams/reservoirs which are unlikely to be adopted as a new water source. Since water demand is expected to grow mainly in the centre of the Phnom Penh Capital and in the southern part of the Capital, seven candidate water source sites were selected from each of the following districts (***Table 5.2.1***), along the four rivers that flow down the Phnom Penh Capital (***Figure 5.2.1***).

Table 5.2.1 Candidate Water Sources Surveyed

NO.	DISTRICT	RIVER SECTION	REASON OF CHOICE
1	Bakheng	Upper reaches of the Mekong River (from the northern administrative district to the end of the Chroy Changvar peninsula)	Water source with good quantity and quality, response to the expansion of Bakheng WTP.
2	Boeng Thom	Upper reaches of the Prek Thnot River in the Phnom Penh Capital	Advantageous location for water supply to the southwestern part of the Capital, new land acquisition of water intake and WTP is relatively easy, but inappropriate as a water source due to restrictions on water rights and flow rate reduction in the dry season.

NO.	DISTRICT	RIVER SECTION	REASON OF CHOICE
3	Ta Mouk	Upper reaches of the Sap River	PPWSA has a vast land area, which makes it easy to secure land for a WTP and is an advantageous location for water supply to the south.
4	Svay Rolum	Lower reaches of the Bassac River (in the Kandal province adjacent to Phnom Penh Capital)	Location advantageous for water supply to the southern part of the Capital, relatively easy to acquire new land for water intake and WTP.
5	Nirodh/Koh Norea	Lower reaches of the Mekong River (the end of the Chroy Changvar peninsula to southern administrative district)	Good quality and good water source, response to expansion of Nirodh WTP and response to new construction of Koh Norea WTP.
6	Khasach Kandal	Opposite bank to the Phnom Penh Capital in the upper reaches of the Mekong River (near Koh Dach and Koh Oknha Tei)	Water source with good quantity and quality, response to new construction of Khasach Kandal WTP.
7	Setbou	Upper reaches of the Bassac River in the Kandal Province	Advantageous location for water supply around the new airport, new land acquisition of water intake and WTP is relatively easy.

Source: JICA Survey Team (2021)

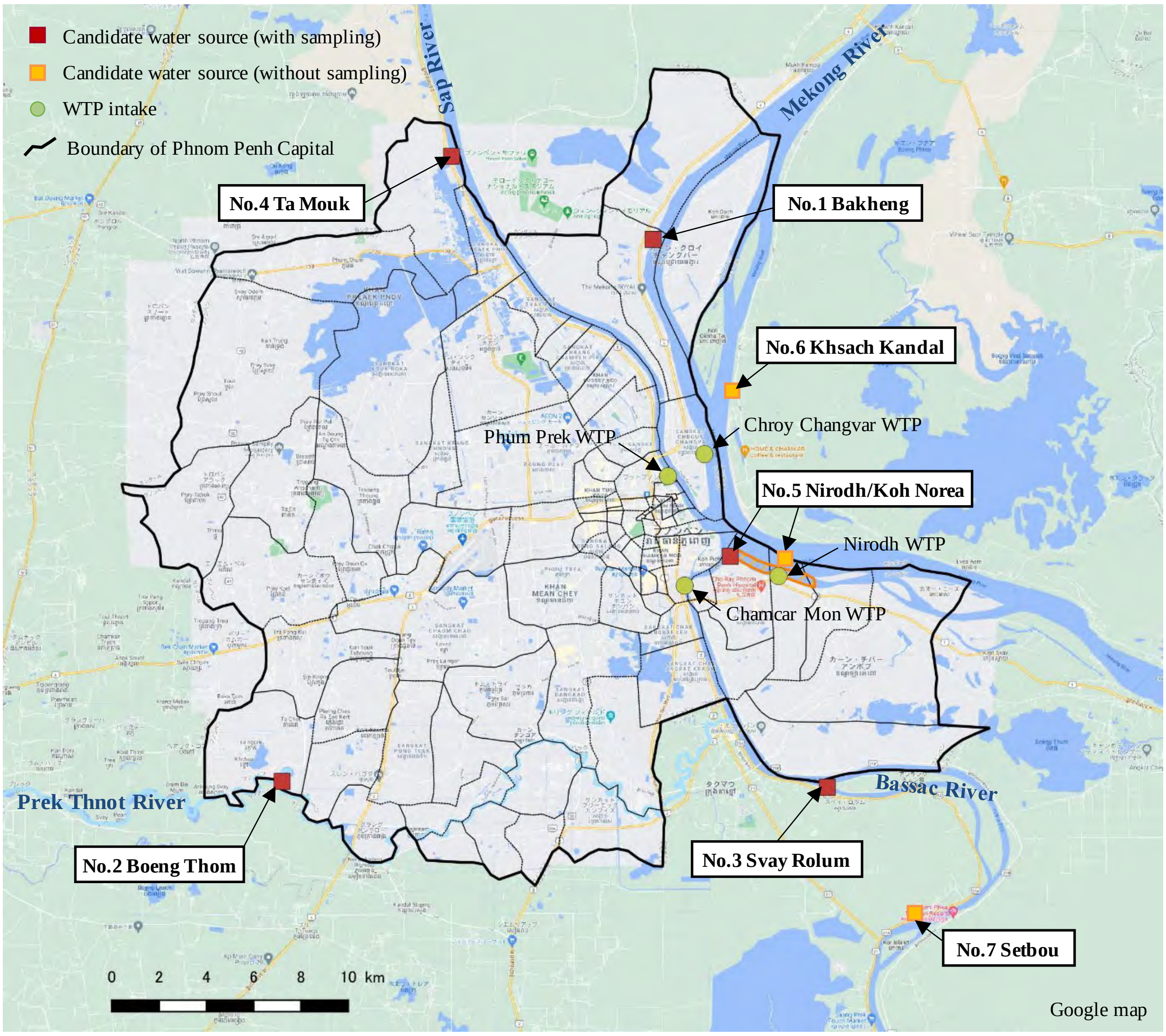


Figure 5.2.1 Location Map of Candidate Warter Resource and River Water Quality Survey
Source: JICA Study Team (2021)

The location of the WTP is also an important factor in determining the raw water intake point. However, in this survey, the availability of each candidate water source was evaluated in terms of water quantity and water quality followed by the potential location of the raw water intake facility and WTP. Alternatively, the candidate sites for raw water intake were examined in consideration of the possibility of land acquisition. The location of existing WTPs and those under construction, and land already acquired by PPWSA are given a preference. ***Table 5.2.2*** shows information on the location of the WTPs.

Table 5.2.2 Location of WTP

Type	WTP	Status	Requirement	Correspondence to Raw Water Intake Candidate
A	Bakheng WTP	Under construction, Construction of raw water intake facility for both of Phase I and Phase II	PPWSA owned land (2 ha) Response to Phase III	No.1
B	Nirodh WTP Koh Norea WTP	Existing New construction	Phase III Land allocated to PPWSA in Koh Norea (2 ha)	No.5
C	New WTP (Ta Mouk)	New construction	Newly constructed reclaimed site in the Ta Mouk Lake in northern Phnom Penh (25 ha)	No.4
D	New WTP	New construction	New site selection and purchase/ securing land required	No.3, No.6, No.7
E	New WTP (Boeng Thom)	The Boeng Thom WTP was planned but cancelled.	It is necessary to select a new site and purchase/secure it. However, construction is not recommended due to inadequate water sources.	No.2

Source: JICA Study Team (2021)

5.2.2 Water Quality Survey

To check the status and to complement past water quality data monitored by the relevant authorities, possible locations of WTPs were selected and surveyed during this project period. Outline of the survey is as follows:

- ✓ Sampling date: 22 May 2020 (dry season), 21 Sep. 2020 (wet season)
- ✓ Sampling method: using pump on a boat
- ✓ Parameters analysed: 37 (physical, mineral, chemical, and biological parameters)

The outline of the sampling points is shown in ***Table 5.2.3***.

Table 5.2.3 Overview of Water Quality Survey

No.	SAMPLING POINT			LOCATION OUTLINE
	LOCATION NAME	LAT.	LON.	
1	Bakheng	11.670696	104.918444	Mekong upstream, near Bakheng WTP site (under construction), northern area
2	Boeng Thom	11.460925	104.774503	Prek Thnot River, near the new WTP projected area, south-western area
3	Svay Rolum	11.459593	104.985907	Bassac River, south-eastern area
4	Ta Mouk	11.703256	104.840422	Sap River, northern area
5	Niroth	11.548520	104.948501	Mekong downstream, near the diversion of Bassac River, eastern area

Source: JICA Study Team (2021)

The results of this survey are shown in ***Table 5.2.4*** and ***Table 5.2.5***. As shown in the previous section (**5.1.2**), PPWSA has been measuring raw water quality to monitor the adequacy as drinking water source at the intake facilities for more than 15 years (except at the Nirodh WTP intake). Review of such past data reveals no serious issues related to water quality at all locations. The outline of the raw water quality at each water source candidate site is as follows:

Dry season

- ✓ Turbidity and color: While turbidity is almost the same as previously observed levels, color values are high at all points. Necessity for strengthening treatment such as coagulation and precipitation should be considered.
- ✓ Other general items: No problems are found in items other than the above (alkalinity, hardness, BOD).
- ✓ Ammonia nitrogen: Was found to be high at all points but it is still within the range of previously observed levels and no additional processing steps are required at this time. Monitoring should be continued to evaluate whether further processing is necessary in the future.
- ✓ Nitrate / nitrite nitrogen: Nitrate nitrogen is high at Boeng Thom, and nitrite nitrogen tends to be high at Boeng Thom, Svay Rolum, and Nirodh but neither greatly exceed previously observed levels . It is considered that there is significant influence of the inflow of domestic wastewater or agricultural wastewater.
- ✓ Metals: Iron and manganese values are sufficiently low. Overall, aluminium values are very high and may affect the coagulation and sedimentation process so additional treatment enhancements should be considered. No highly harmful metals have been detected.
- ✓ E. coli: The value in Ta Mouk is high, and it is considered that there is significant influence of domestic wastewater. The necessity for enhanced chlorination treatment should be considered.

Wet season

- ✓ Turbidity and color: Color at Ta Mouk is high, and process enhancements such as coagulation precipitation should be considered.
- ✓ Other general items: Electrical conductivity and alkalinity tend to be high at all points, and the necessity of adding a pH adjuster should be considered.
- ✓ Ammonia nitrogen: Was found to be about the same as previously observed levels, and there is no problem.
- ✓ Nitrate / nitrite nitrogen: Was found to be about the same as previously observed levels, and there is no problem.
- ✓ Metals: Iron values tend to be high in Bakheng, Boeng Thom, and Svay Rolum, and aluminium values tend to be high at all points. As in the dry season, there is a risk of reduced efficiency of the coagulation sedimentation process, and the necessity for strengthening should be considered. No highly harmful metals have been detected.
- ✓ E. coli: Compared with previously observed values, current value is about the same or less, and the same processing process can be used.

Table 5.2.4 Water Quality Survey Results for Dry Season (May, 2020)

NO.	PARAMETER	UNIT	RESULT (RAW WATER)					DRINKING WATER STANDARD (TREATED)	PAST RECORD* (MAY, 2006-2020) AVERAGE, RANGE
			No.1 Bakheng	No.2 Boeng Thom	No.3 Svay Rolum	No.4 Ta Mouk	No.5 Nirodh		
1	pH	-	8.19	7.3	7.72	7.58	8.24	6.5-8.5	7.50 (7.16-8.33)
2	Temperature	^oC	31.2	29.7	31.9	30.9	32.4		30.3(26.4-32.7)
3	Conductivity	μs/cm	266	149.7	304	187.4	268	<1600	168(125-259)
4	TDS	mg/L	116	66	133	82	117	<800	89(63-147)
5	Turbidity	NTU	4	42	20	28	22	<5	21(8-125)
6	DO	mg/L	5.02	3.72	4.67	5.07	6.45		4.6(2.58-8.5)
7	Color	mg/L Pt	105	520	160	230	160	<5	7.7(2.0-125)
8	Alkalinity	mg/L	21	39	47	43	50		57(42-81)
9	Hardness	mg/L	86.6	34.7	83.7	51.4	73.9	<300	64.3(39-116)
10	BOD	mg/L	1.1	1.5	2.2	1.1	2.7		
11	COD_{cr}	mg/L	11	13	7	4	10		
12	NH_4-N	mg/L	0.81	1.02	1.38	0.60	0.69	<1.5	0.10(0-1.2)
13	Cyanide (CN^-)	mg/L	0	0.012	0.002	0.004	0.003		0.002(0-0.02)
14	Chloride (Cl^-)	mg/L	13.6	4.6	17.8	7.7	13.5	<250	22.5(5.7-48)
15	Fluoride (F^-)	mg/L	BDL	BDL	BDL	BDL	BDL	<1.5	0.17(0-0.44)
16	NO_2-N	mg/L	BDL	0.02	0.082	BDL	0.030	<3	0.007(0.001-0.09)
17	NO_3-N	mg/L	0.32	1.90	0.50	0.68	0.43	<50	0.64(0-2.5)
18	Sulphate (SO_4^{2-})	mg/L	40	12	38	13	41	<250	11(1-34)
19	Total Bacteria	cfu/100ml	1,500	200	1,100	26,700	28,100		
20	Fecal Coliform	MPN/100ml	150	920	430	1,500	360	0	314(80-37650)
21	Manganese (Mn)	mg/L	BDL	0.02	BDL	BDL	BDL	<0.1	0.019 (0-0.2)
22	Iron (Fe)	mg/L	0.05	0.09	BDL	BDL	BDL	<0.3	0.069(0-1.25)
23	Calcium (Ca)	mg/L	23.8	8.6	21.5	14	23	<80	17(9.6-28)
24	Sodium (Na)	mg/L	4.9	7.5	9.4	5.6	5.2	<250	
25	Magnesium (Mg)	mg/L	6.6	3.2	7.3	4	4	<36	5.5(3.2-11)
26	Aluminum (Al)	mg/L	0.18	5.1	0.7	1.1	0.8	<0.2	0.013(0-0.31)
27	Antimony (Sb)	mg/L	BDL	BDL	BDL	BDL	BDL		
28	Arsenic (As)	mg/L	BDL	BDL	BDL	BDL	BDL	<0.01	
29	Barium (Ba)	mg/L	0.03	0.04	0.05	0.03	0.08	<0.7	
30	Cadmium (Cd)	mg/L	BDL	BDL	BDL	BDL	BDL	<0.003	
31	Chromium (Cr)	mg/L	BDL	BDL	BDL	BDL	BDL	<0.05	0.014(0-0.06)
32	Copper (Cu)	mg/L	BDL	BDL	BDL	BDL	BDL	<1	0.018(0-0.09)
33	Lead (Pb)	mg/L	BDL	BDL	BDL	BDL	BDL	<0.01	
34	Mercury (Hg)	mg/L	BDL	BDL	BDL	BDL	BDL	<0.001	
35	Nickel (Ni)	mg/L	BDL	BDL	BDL	BDL	BDL		
36	Selenium (Se)	mg/L	BDL	BDL	BDL	BDL	BDL		
37	Zinc (Zn)	mg/L	BDL	BDL	BDL	BDL	BDL	<3	0.029(0-0.2)

BDL: Below Detection Limit, *: based on the measured data (raw water) at WTP site of PPWSA.
Source: JICA Study Team (2021)

Table 5.2.5 Water Quality Survey Results for Wet Season (September, 2020)

NO.	PARAMETER	UNIT	RESULT (RAW WATER)					DRINKING WATER STANDARD (TREATED)	PAST RECORD* (SEP., 2006-2020) AVERAGE, RANGE
			No.1 Bakheng	No.2 Boeng Thom	No.3 Svay Rolum	No.4 Ta Mouk	No.5 Nirodh		
1	pH	-	7.36	7.07	7.27	6.82	7.26	6.5-8.5	7.34(7.14-7.78)
2	Temperature	ºC	28.7	29.1	28.5	29.5	28.6		28.0(27.1-29.9)
3	Conductivity	μs/cm	131.2	104.6	138.8	125.4	144.6	<1600	102.5(65-127)
4	TDS	mg/L	58	46	59	55	64	<800	52.3(35-87)
5	Turbidity	NTU	88	170	42	16	52	<5	174.3(24-478)
6	DO	mg/L	6.16	6.07	6.72	6.19	5.98		5.9(4.37-8.37)
7	Color	mg/L Pt	65	320	65	25	40	<5	41.3(19-156)
8	Alkalinity	mg/L	52	94	84	72	81		40.9(27-54)
9	Hardness	mg/L	47.6	29.5	45.6	43.4	49.2	<300	44.7(32-60)
10	BOD	mg/L	0.76	0.87	1.32	2.99	0.98		
11	COD_{cr}	mg/L	5	2	3	2	10		
12	NH_4-N	mg/L	0.15	0.26	0.31	0.21	0.22	<1.5	0.32 (0.04-3.39)
13	Cyanide (CN^-)	mg/L	ND	ND	0.002	ND	ND		0.002(0-0.008)
14	Chloride (Cl^-)	mg/L	13	6.2	7.8	7	9.4	<250	18.4(1.05-43)
15	Fluoride (F^-)	mg/L	0.55	0.05	0.05	0.55	0.5	<1.5	0.083(0-0.64)
16	NO_2-N	mg/L	0.01	0.01	0.06	0.02	0.01	<3	0.006(0.002-0.03)
17	NO_3-N	mg/L	0.3	1.6	0.5	0.1	0.3	<50	0.65(0-2.3)
18	Sulphate (SO_4^{2-})	mg/L	2	5	1	0.2	2	<250	2.3(0-15)
19	Total Bacteria	1ml/H_2O	1410	1010	640	1860	430		
20	Fecal Coliform	MPN/100ml	72	150	74	150	92	0	1262.8(75-50720)
21	Manganese (Mn)	mg/L	0.091	0.135	0.071	0.049	0.057	<0.1	0.024(0-0.2)
22	Iron (Fe)	mg/L	3.96	6.47	3.04	0.82	1.54	<0.3	0.108(0-2.5)
23	Calcium (Ca)	mg/L	13.07	7.248	12.55	11.95	13.77	<80	12.7(8.4-16.8)
24	Sodium (Na)	mg/L	3.72	5.52	3.84	4	3.99	<250	
25	Magnesium (Mg)	mg/L	3.64	2.77	3.47	3.29	3.6	<36	2.9(1.5-4.9)
26	Aluminum (Al)	mg/L	2.62	4.76	2.01	0.58	0.93	<0.2	0.007(0-0.17)
27	Antimony (Sb)	mg/L	BDL	BDL	BDL	BDL	BDL		
28	Arsenic (As)	mg/L	0.0052	0.005	0.003	0.001	0.003	<0.01	
29	Barium (Ba)	mg/L	0.033	0.0436	0.03	0.027	0.033	<0.7	
30	Cadmium (Cd)	mg/L	BDL	BDL	BDL	BDL	BDL	<0.003	
31	Chromium (Cr)	mg/L	BDL	BDL	BDL	BDL	BDL	<0.05	0.008(0-0.09)
32	Copper (Cu)	mg/L	BDL	BDL	BDL	BDL	BDL	<1	0.010(0-0.11)
33	Lead (Pb)	mg/L	BDL	BDL	BDL	BDL	BDL	<0.01	
34	Mercury (Hg)	mg/L	BDL	BDL	BDL	BDL	BDL	<0.001	
35	Nickel (Ni)	mg/L	BDL	BDL	BDL	BDL	BDL		
36	Selenium (Se)	mg/L	BDL	BDL	BDL	BDL	BDL		
37	Zinc (Zn)	mg/L	BDL	BDL	BDL	BDL	BDL	<3	0.040(0-0.28)

BDL: Below Detection Limit, *: based on the measured data (raw water) at WTP site of PPWSA.
Source: JICA Study Team (2021)

Table 5.2.6 Comparison of Water Quality at Candidate Water Sources (Main Items Only)

PARAMETER	UNIT	ANNUAL (TOP: AVERAGE, BOTTOM: RANGE)			DRY SEASON			WET SEASON		
		Mekong	Sap	Bassac	Mekong	Sap	Bassac	Mekong	Sap	Bassac
Temperature	^oC	28.9 23.7-32.7	28.8 25.3-31.5	28.5 25.2-31.2	29.1	29.0	28.6	28.7	28.7	28.4
pH	-	7.86 7.17-8.48	7.29 6.78-7.99	7.44 6.88-8.11	8.08	7.3	7.5	7.69	7.3	7.4
Conductivity	µs/cm	160.0 83-259	115.0 62-258	134.5 72-259	193.3	120.2	153.2	135.8	111.2	120.1
TDS	mg/L	80.7 42-161	60.6 31-147	67.5 36-130	96.7	64.1	76.7	69.1	68.1	60.5
Turbidity	NTU	110.6 10-469	106.7 12-427	135.6 8-799	18.7	69.2	55.1	177.4	134.0	197.1
DO	mg/L	7.33 4.53-8.68	5.02 1.76-7.18	7.23 6.18-8.5	7.34	4.43	7.18	7.32	5.36	7.28
Color	mg/L Pt	30.8 1.98-228	39.4 4.53-147	35.7 4.91-182	7.71	40.6	31.7	47.7	38.5	38.7
Alkalinity	mg/L	57.6 27-80	41.6 23-78	45.5 24-79	70.0	42.4	50.4	48.7	41.0	41.8
Hardness	mg/L	65.1 31-98	46.1 23-104	52.1 24-116	79.1	45.9	57.9	55.0	46.2	47.6
BOD	mg/L	2.66 0.59-7.00	4.40 1.60-7.48	3.49 0.73-6.96	1.85	5.11	3.41	3.24	3.89	3.56
NH_4-N	mg/L	0.23 0-3.39	0.42 0-2.3	0.22 0-1.48	0.09	0.46	0.18	0.32	0.40	0.25
Chloride (Cl^-)	mg/L	22.2 4.8-52	24.2 1-55	22.0 7.4-50	21.8	24.5	22.4	22.4	23.9	21.8
Nitrate Nitrogen (NO_3-N)	mg/L	0.90 0-2.4	1.17 0.33-7.8	1.06 0-3.54	0.74	1.21	1.09	1.02	1.14	1.04
Sulphate (SO_4^{2-})	mg/L	11.1 0-30	5.25 0-32	7.39 0-34	15.5	5.07	9.13	7.94	5.38	6.06
Fecal Coliform	MPN/ 100ml	1,077 43-10,825	6,061 130-108,050	875 36-11,867	717	5654	882	1340	6357	870
Manganese (Mn)	mg/L	0.034 0-0.33	0.043 0-0.30	0.036 0-0.23	0.032	0.050	0.035	0.035	0.038	0.037
Iron (Fe)	mg/L	0.37 0-8.12	0.13 0-1.14	0.49 0-6.88	0.062	0.15	0.30	0.59	0.11	0.64
Aluminum (Al)	mg/L	0.048 0-0.193	0.013 0-0.082	0.01 0-0.11	0.051	0.013	0.011	0.045	0.013	0.011
Chromium (Cr)	mg/L	0.019 0-0.08	0.016 0-0.05	0.013 0-0.03	0.019	0.017	0.014	0.020	0.015	0.013
Copper (Cu)	mg/L	0.023 0-0.12	0.020 0-0.10	0.020 0-0.11	0.025	0.022	0.019	0.022	0.019	0.021
Zinc (Zn)	mg/L	0.049 0-0.2	0.049 0-0.28	0.038 0-0.17	0.048	0.050	0.036	0.050	0.048	0.040

Source: PPWSA

5.2.3 Sustainability of Water Source

(1) Impact due to Hydropower Dams in the Upstream Mekong River and Climate Change

According to the study by the Mekong River Commission (MRC), river flow forecasts based on various warming scenarios show that the impact of climate change up to 2060 will significantly affect the flow rate and water level of the Mekong River and will make them severely fluctuate. The minimum daily discharge in the dry season in Kratie as of 2060 (based on 2007) is predicted as -43 to +20% for climate change only and -13 to +65% for climate change plus dam development (***Table 5.2.7***).

As mentioned in ***Chapter 3***, it is thought that the river flow in the dry season will increase on average as dam construction and operation in the upper basin of the Mekong River progress. However, the annual fluctuations will rather increase due to the effects of climate change. Considering the range of MRC forecast results as the range of annual fluctuations (upper and lower limits), it would be safer to assume that the annual minimum daily flow rate would drop to -43%.

At present, there might be a year when the annual minimum flow rate in Chroy Changvar drops from 1,889 m^3/s to about 1,077 m^3/s (assuming that the point near Phnom Penh has the same fluctuation range as Kratie).

Since the water demand is about 0.61% of this flow rate, the total flow rate is not affected by raw water intake. However, the minimum low water level might drop by 0.18 m (0.5 m AMSL at Chroy Changvar), and it is predicted that the degree of flow rate and water level drop will be larger toward the downstream.

Reflecting these predictions, the minimum low water level at each point should be considered in the design of the raw water intake facility. Predictions of minimum low water level fluctuations due to climate change impacts with/without dam development are shown in ***Figure 5.2.2***.

Table 5.2.7 Impact of Dam Construction and Climate Change on Hydrological Factors of the Mekong River (Kratie, compared to 2007)

Hydrological Factor		Impact		Only Climate Change		Climate Change and Dam Operation	
				2030	2060	2030	2060
River Discharge (Average)	Dry season	Min	%	-25	-43	-6	-29
		Ave		8	5	27	24
		Max		30	45	46	60
River Water Level (average)	Dry season	Min	m	-0.66	-1.13	-0.12	-0.74
		Ave		0.17	0.11	0.73	0.66
		Max		0.71	1.08	1.18	1.39
Drought	Daily discharge	Min	%	-26	-43	17	-13
		Ave		-3	-4	53	56
		Max		11	20	62	65
	Daily water level	Min	m	-0.37	-0.61	0.24	-0.18
		Ave		-0.04	-0.05	0.73	0.77
		Max		0.15	0.28	0.86	0.90

Source: Extract from MRC material

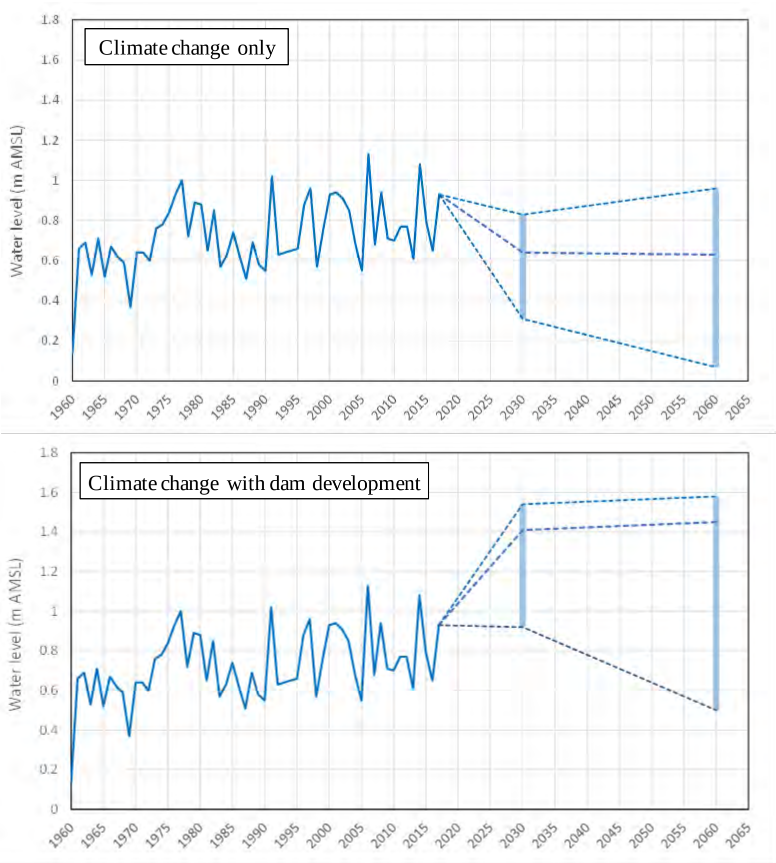


Figure 5.2.2 Future Minimum Water Level Prediction Considering the Effects of Dams and Climate Change (Chroy Changvar)

Source: JICA Study Team based on MRC and MOWRAM data (2021)

(2) Reduction of River Water Level

In the dry season of 2019-2020, a noticeable drop in water level, which seems to be an impact of climate change, was seen particularly in the Sap River. ***Figure 5.2.3*** and ***Figure 5.2.4*** show the changes in the observed water level through a year and from November to May of the following year in recent years (only typical years).

According to MOWRAM and MRC analysis, the water level was record-low due to little rainfall in the catchment area of Tonle Sap Lake and low water flow in the Mekong River. During the period from early December 2019 to mid-February 2020, the water level was the lowest ever due to the low flow in the wet season, but after mid-February it was lower than normal but not the lowest ever. This reduced the availability of the entire Sap River, but the water level and flow rate would not fall below the minimum low water level (Prek Kdam, 0.43 m AMSL, May 17, 1970), which any intake facility would lose their water intake function. When designing intake facilities, it is necessary to use the minimum low water level at the intake point as a reference.

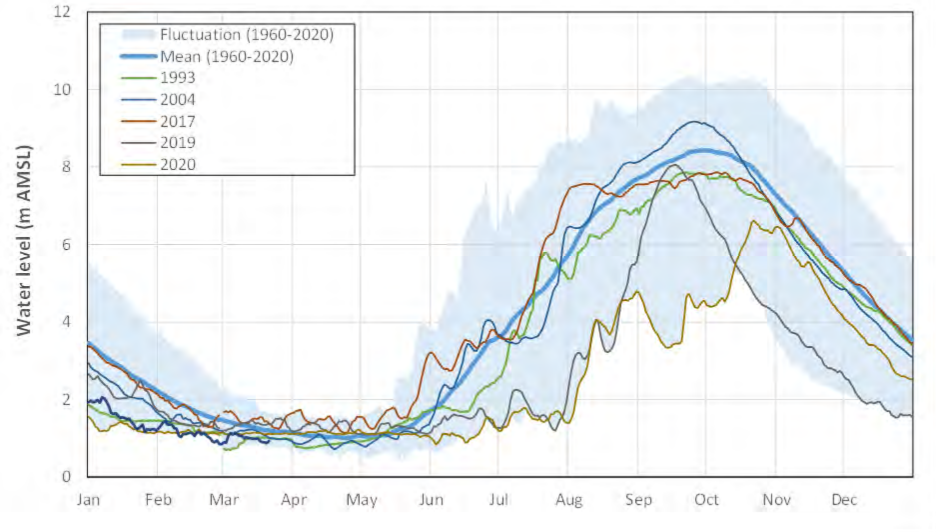


Figure 5.2.3 Annual Fluctuation of Water Level in Sap River (Prek Kdam)
Source: JICA Study Team based on MOWRAM data (2021)

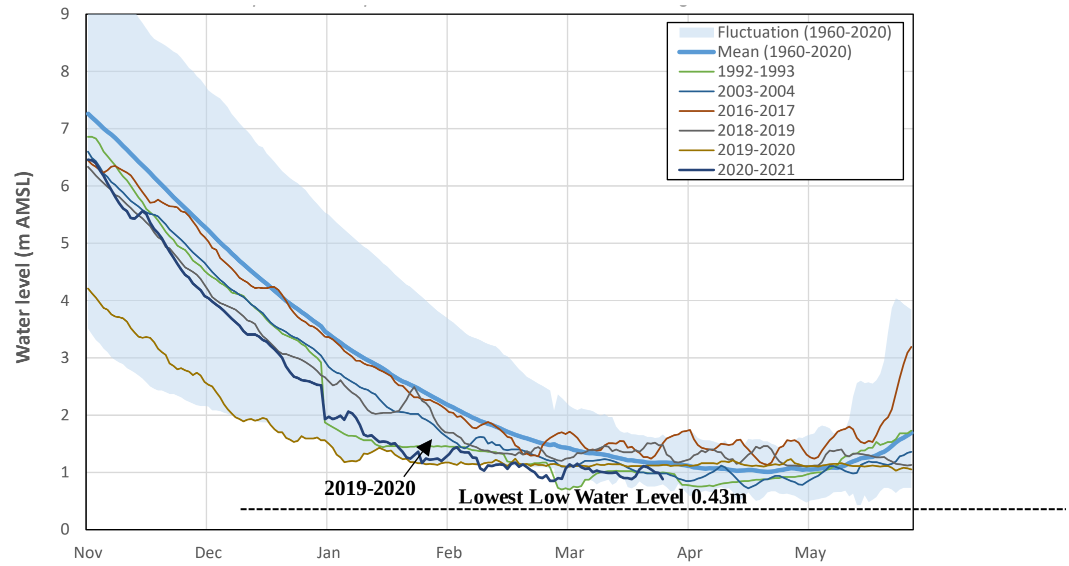


Figure 5.2.4 Water Level Fluctuation in Sap River in Dry Season (Nov. – May, Prek Kdam)
Source: JICA Study Team based on MOWRAM data (2021)

(3) Change in Water Quality

1) Impact due to Urban Drainage and Sewerage

In the Phnom Penh Capital Sewage and Drainage Improvement Project (2014-2016) by JICA, the capital area was divided into 27 drainage areas, and drainage management plans were formulated by improving drainage channels, pumping stations, etc., and projects based on them are currently being implemented. ***Figure 5.2.5*** shows the drainage area and drainage points to each river based on the plan. Drainage points are planned for all four rivers (3 to the Mekong, 3 to the Sap, 3 to the Bassac and 8 to the Prek Thnot River).

As shown in ***Figure 5.2.5***, two sewerage development areas (Cheung Aek sewage treatment area and Ta Mouk sewage treatment area) are planned and treated water will flow into Cheung Aek Lake and Ta Mouk Lake, respectively. The above project report estimated the emission of pollution load and its reduction effect in 2035 by the sewerage facility to be developed, in consideration of urban development and population growth. ***Table 5.2.8*** shows the prediction of reduction of BOD emission load by the operation of sewerage facilities. Although the total amount of load generated will increase significantly, the BOD emission load from both drainage areas will be significantly reduced by the development of sewerage facilities. On the other hand, emission loads from areas where there are no plans for sewerage development were estimated to be more than double compared to 2015 and will increase by about 60% even after treatment. Therefore, in some areas, the water quality would deteriorate as the pollution load increases.

In addition, the improvement of rainwater drainage was also being promoted with the development of urban drainage facilities in each drainage zone with the target year of 2035. ***Figure 5.2.5*** also shows the river drainage outfalls of rainwater from each drainage area. From the positional relationship with the water intake sources that are candidates in this survey, the candidate sites for the Sap and upper Mekong rivers are not so much affected by rainwater drainage, but in the lower Mekong, Bassac, and Prek Thnot rivers, candidate intake points are located downstream of several rainwater drainage points. In general, urban surface runoffs and effluents contain a variety of household and industrial sources of pollutants, and the concentration of pollutants is likely to increase, at least immediately downstream of the drainage point. In order to reduce the adverse effects of these on raw water, the intake point should be selected so that it is located upstream of the rainwater drainage point.

In addition, land reclamation and development of lakes and wetlands are ongoing in and around Phnom Penh. As shown in ***Figure 5.2.6***, two lakes, which treated sewage water discharge into, have also begun to be reclaimed. It is estimated that the function as temporary retention of discharge water, deposition of particulate materials and purification of water, and other natural services will be lost. Therefore, in the short to medium term, it is estimated that the contamination of river water by pollutants contained in surface runoff will increase, leading to high treatment costs in water quality management work.

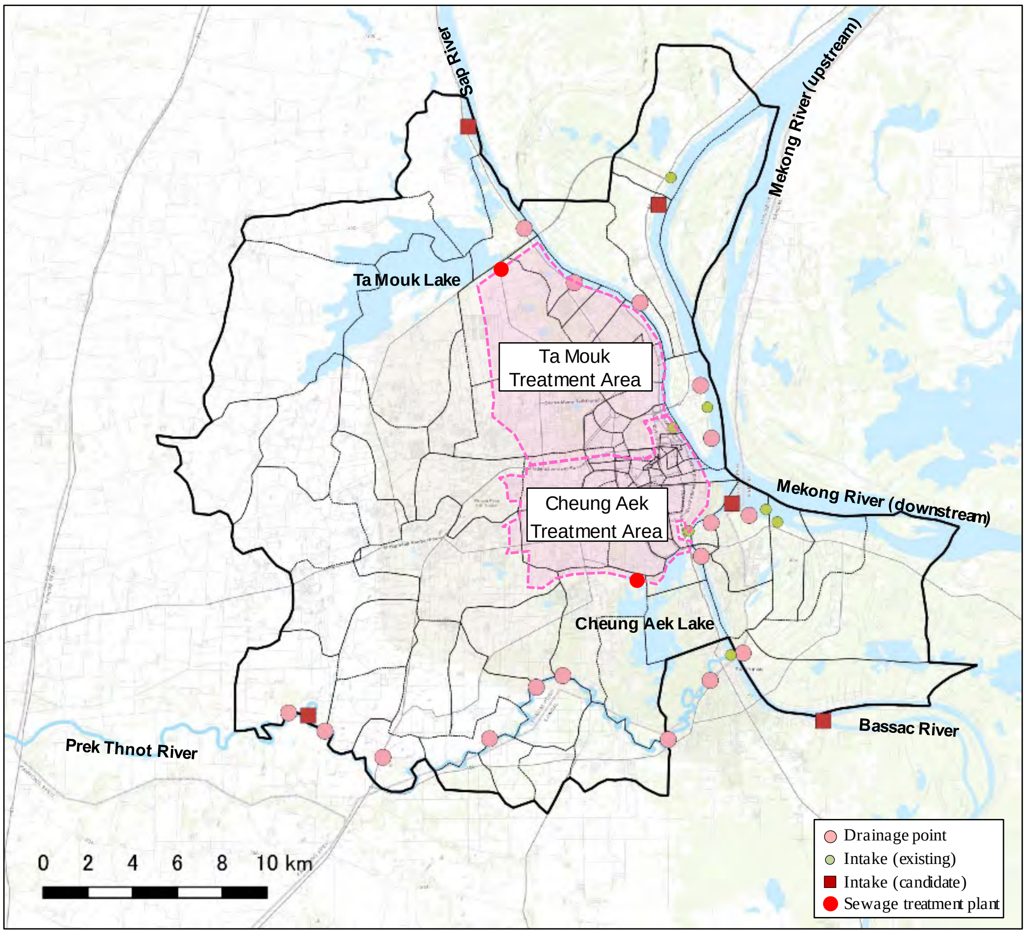


Figure 5.2.5 Drainage Points to Rivers in Wastewater Treatment Plans

Source: Created by the survey team based on the Report on Phnom Penh Capital Sewerage and Drainage Improvement Project (2016)

Table 5.2.8 Contamination Load Reduction Effect by Maintenance and Operation of Sewerage Facilities

Region/Treatment Area	Area (ha)	Generation (t/day)		After Treatment (t/day)	
		2015	2035	2015	2035
Cheung Aek Treatment Area	4,701.9	40.7	49.9 (+23%)	32.6	7.8 (-76%)
Ta Mouk Treatment Area	6,019.2	15.5	22.0 (+42%)	12.4	3.5 (-72%)
Other area	57,124.9	19.9	41.8 (+110%)	15.9	25.2 (+58%)
Total	67,846.0	76.1	113.7 (+49%)	60.9	36.5 (-40%)

Source: Created by the survey team based on the Report on Phnom Penh Capital Sewerage and Drainage Improvement Project (2016)

Cheung Aek Lake (Nov. 2013)

Cheung Aek Lake (Feb. 2021)

Ta Mouk Lake (Feb. 2014) | Ta Mouk Lake (May 2021)

Figure 5.2.6 Water Area Development Status around the Phnom Penh Capital

Source: JICA Study Team (2021)

2) Future Change in Water Quality

In the Sap River, which is one of the water source candidates, there is concern about deterioration of water quality due to increased algae loads brought by the decrease in the outflow to Tonle Sap Lake, the decrease in the reverse flow from the Mekong River, and the decrease in the circulation of the lake water, raised by the recent climate change.

A sewage treatment plant is planned to be constructed in northern Phnom Penh, and it is likely that the effluent water will be discharged to the Sap River. In addition, it is expected that the inflow of domestic wastewater and industrial wastewater into each river in urban areas or suburbs will increase in all other candidate rivers. ***Table 5.2.9*** summarizes concerns and countermeasures for future water quality of the candidate water sources.

Table 5.2.9 Concerns about Future Water Quality

VIEWPOINT	CONCERNS	COUNTERMESURE PROPOSAL
pH instability	High hardness, or alkalinity. Since the pH becomes unstable during the water treatment process, an adjuster is required, which is very time-consuming.	Change of coagulant (sulfuric acid band) and injection of sulfuric acid, caustic soda, slaked lime, etc. for pH adjustment.
Peak concentration of ammonia	As the peak concentration increases, chlorine consumption increases, and the amount of chlorine injected in the pre-treatment increases. At the same time, if the amount of organic matter is high, there is a high possibility that dangerous by-products (chlorine compounds) will be produced. Ammonia treatment process needs to be modified.	Take necessary treatment steps such as aeration, pre-treatment (biological treatment), chlorine treatment, etc. according to the ammonia concentration of the raw water.
High organic matter concentration	high chlorine requirement for oxidation treatment of pathogenic bacteria organic matter, leading to by-products of chlorine compounds, clogging, and loss of water volume during the treatment process.	Chlorine treatment for high-level pathogenic bacteria is required, and cost-effective treatment steps such as aeration, pre-treatment (biological treatment), and chlorination are taken according to the organic matter concentration and the number of microorganisms in the raw water.
Deterioration of water quality in the dry season	The water quality of the Sap River in the dry season is not good due to the influence of upstream pollution. For example, compared to Mekong and Bassac, DO is 30% or more lower, organic matter content (BOD) is higher, fecal Escherichia coli is 10 times higher, etc. Participation in discussions, etc.)	Drainage improvement (cooperation for drainage management in the Tonle Sap Lake basin, participation in discussions on countermeasures as a stakeholder, etc.)
Discharge from sewage treatment plant	A sewage treatment plant is planned to be constructed in the northern part of Phnom Penh (discharge of treated water into Ta Mouk Lake), and there is a possibility that the quality of raw water would be unstable due to the inflow of treated water into the river.	Placed as upstream as possible from the point of inflow of treated sewage into the river

Increase in inflow of pollutant load contained in surface runoff	The pollutant load due to surface runoff increases due to urbanization and development of unused land (especially reclamation of water body), causing deterioration of river water quality, which is the water source.	The water intake point should be planned to be located upstream of the drainage inflow point.
Highly toxic microorganisms	Toxicity by cyanobacteria, especially in the Sap River (detected in Tonle Sap Lake, and there is concern that the impact on the downstream area will spread in the future) Cyanobacteria are difficult to remove and require post-ozone treatment and activated carbon treatment, resulting in high cost.	Prediction of future trends through continuous monitoring and accumulation and analysis of scientific knowledge. Consideration of introduction of ozone treatment process

Source: JICA Study Team (2021)

PPWSA is not the government agency responsible for maintaining river water quality but efforts must be made to control the deterioration of raw water quality, even indirectly, and keep it within an appropriate range in order to maintain the capacity of treated water supply.

5.2.4 Geographical and Topographical Conditions

(1) Difference in Elevation and Distance

Table 5.2.10 summarizes the elevation difference and distance between the candidate water source site and the candidate WTP site. The distance between the water intake and the WTP, and the water demand area has a great influence on the efficiency of water supply and distribution. The farther the water intake and the WTP are, the longer the closed conduit for the raw water becomes, and there is a high possibility that maintenance will take time and money.

Table 5.2.10 Positional Relationship between the Candidate Water Source Site and the Candidate WTP Site

WTP	LOCATION OF RAW WATER INTAKE	DISTANCE BETWEEN WTP AND RAW WATER INTAKE	DIFFERENCE IN ELEVATION	REMARKS
Bakheng Phase III	Bakheng district on the right bank of the Mekong River	Approx. 2 km	Approx. 5.7 m	Utilizing the existing waterway as a route
Nirodh Phase III	Right bank of Mekong River Koh Norea	Approx. 3 km	Approx. 2.2 m	There is a bridge between the landfill and
Koh Norea	Koh Norea on the right bank of the Mekong River	Close to Koh Norea (on the same site)	No elevation difference	Land is planned to be secured, but the detailed location is undecided.
Ta Mouk	Lake Ta Mouk reclaimed land	Approx. 7 km	Approx. 2.0 m	Part of the route has not been constructed
Khsach Kandal	Khsach district on the left bank of the Mekong River	Approx. 200 m	No elevation difference	Waterworks and water intake facilities are adjacent
New Airport City	Bassac river right bank Setbou district	Approx. 500 m	Approx. 0.8 m	

Source: JICA Study Team (2021)

(2) Riverbank

In the Mekong River, there are some places where riverbank erosion is progressing. ***Figure 5.2.7*** shows the riverbank erosion and revetment development in the upper Mekong River and the Bassac River.

Figure 5.2.8 shows the state of the riverbank at the candidate site for intake of the Sap River. Many of the candidate water intake sites are left as natural riverbanks, and there is evidence that the riverbanks have been eroded during floods. There are only a limited number of sections with appropriate revetment maintenance. It is necessary to carry out revetment work and riverbed protection work at the same time as the construction of the water intake facility.

Section of bank protection developed in the Mekong River

Section of bank protection developed in the Bassac River

Right bank of Mekong River (Bakheng district)

Right bank of Bassac River (Chamcar Mon intake upstream)

Right bank of Mekong River (Chroy Changvar intake)

Right bank of Bassac River (downstream of Chamcar Mon intake)

Figure 5.2.7 Riverbank erosion and revetment development in the Mekong and Bassac rivers

Source: JICA Study Team based on MOWRAM data (2021)

Right bank (around Ta Mouk area)

Right bank (upstream Phum Prek water intake)

Right bank (around Ta Mouk area)

Right bank (around Phum Prek intake)

Left bank of Sap River (bank protected)

Section of bank protection developed in the Sap River

Figure 5.2.8 Riverbank Maintenance Status of Sap River Intake Candidate Site

Source: JICA Study Team based on MOWRAM data (2021)

(3) Impact due to Reclaimed land

Changes in river flow affect sediment transport, sediment deposition, riverbank erosion, and sandbar formation, and are therefore one of the important factors in the design of intake facilities. Regarding Koh Norea (***Figure 5.2.9***), where reclamation of the Mekong River facing the Nirodh area is underway, MOWRAM (the organization responsible for river management) has not conducted a survey or analysis on the impact of reclamation on the river flow. The right bank of the Mekong River in the Nirodh district (located downstream of the Chaktomuk and Bassac river diversion points), where the Nirodh intake facility is currently located and is being reclaimed, is the place where the riverbed scouring by the flow progresses (river edge). Reclamation of that area would move the scouring site to the central side of the Mekong River and impair the stability of the revetment and riverbed of the reclaimed land. (***Figure 5.2.10***). This is an element to keep in mind when designing and constructing an intake facility.

Figure 5.2.9 Koh Norea location and development plan
Source: Overseas Cambodian Investment Corporation

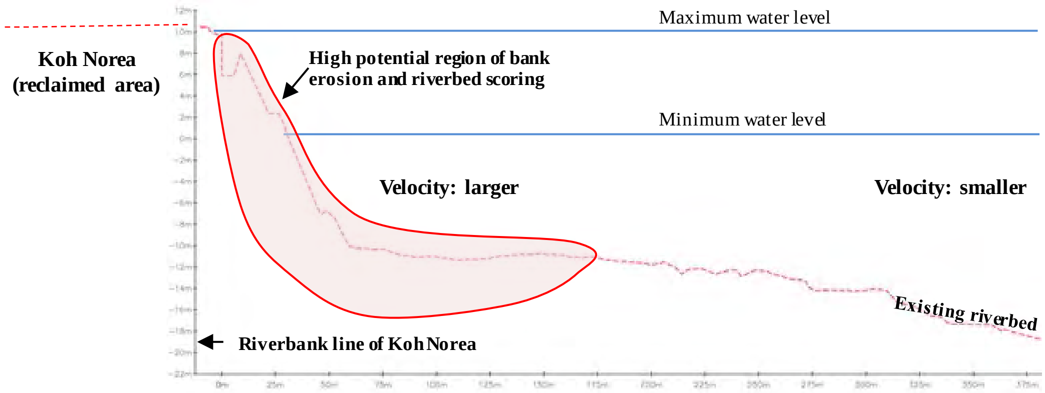


Figure 5.2.10 Cross section of the Mekong River in Koh Norea (near Koh Norea and possible riverbank erosion and bed scouring)
Source: Created by the survey team after adding to SAFEGE, JEB Surveys and Engineering

(4) Regulation and Rule Related to Water Intake

The Government of Cambodia enforced the Water Resources Management Law, which was created with the support of the World Bank, in May 2007, at which time it was trying to formulate a decree on water allocation and licensing as a sub decree. However, there is no announcement or record that it has been enforced so far, and there is currently no clear rule that defines the licensing system for water use (right to take water from rivers).

In order to take in surface water and groundwater as well as rivers, approval by the Ministry of Water Resources and Meteorology (MOWRAM), which is in charge of these management, is required. PPWSA will select a suitable site for the water source, and after undergoing the prescribed procedures for the construction of the water intake facility, it will obtain a formal permit. In essence, a business operator such as PPWSA sends a permit application letter to the Cambodia National Mekong Committee (CNMC) and MOWRAM, and the procedure has been taken to obtain the consent of both agencies. ***Table 5.2.11*** lists the elements described in the letter. Since the examination will be conducted based on these statements, appropriate investigation should be conducted and the information showing the rationale for selection should be organized.

Table 5.2.11 Information Required for Permit Application

CONTENTS OF PERMIT APPLICATION LETTER
- Purpose: Application for permission of water rights - General information on plans for new WTP (water production volume, year of construction, year of completion) - Location of water intake facility (district, river) - Distance from the riverbank to the intake facility in the dry season (clarified that there is no hindrance to the navigation of vessels) - Riverbank protection status - Upper limit of total raw water intake (daily amount) - River flow (annual average) and ratio of water intake - River flow rate (minimum flow rate) and ratio of water intake - Water Treatment method

Source: PPWSA

5.3 CONCLUSION ON WATER RESOURCES

As a conclusion regarding the choice of water sources, the evaluation results of the candidate water source sites are summarized in ***Table 5.3.1***. From the discussions in the previous sections, new water sources able meet the water demand in the Phnom Penh Capital are “Upper Right and Left Bank in the Mekong River”, “Upper Right Bank of the Sap River” and “Upper Right Bank of the Bassac River in the Kandal Province”.

Considering the location of the land owned or planned to be secured by PPWSA and the cost burden of acquiring (purchasing) new land, it is recommended that water sources should be selected from a comprehensive viewpoint with effective use preference of the owned land.

Table 5.3.1 Evaluation Result of Water Source Candidate Site

CANDIDATE WATER SOURCE		CORRESPONDING WTP PLANNED SITE	SECURING WATER INTAKE	WATER QUALITY	SUSTAINABILITY OF WATER INTAKE	GEOGRAPHICAL CONDITION	FACTOR OF INCREASING COST	COMPREHENSIVE EVALUATION
NAME /REGION	DISTRICT							
Mekong River Upper Right Bank in Phnom Penh	Bakheng District	Bakheng Phase III (under construction)	Excellent 204,750 m^3/day	Good	Excellent	Far from demand area	Water conveyance distance	Excellent
Mekong River Upper left bank of Kandal Province	Khsach District, Kandal Province	Khsach Kandal	Excellent 105,000 m^3/day	Good	Excellent	Close to the demand area (planned to be transferred to the capital)	-	Excellent
Mekong River Lower right bank in Phnom Penh	Nirodh District	Nirodh Phase III	Excellent 136,500 m^3/day	Good	Excellent	Close to the demand area	Water conveyance distance	Excellent
	Koh Norea reclaimed land	Koh Norea (River reclamation)	Excellent 157,500 m^3/day	Good	Excellent	Close to the demand area	-	
Sap River Upper right bank in Phnom Penh Capital	Preak Pnov District	Ta Mouk Phases I to III (planned reclamation site)	Excellent 630,000 m^3/day	Water purification possible	Fairly good Water quality concerns	Far from the demand area	Additional purification treatment Water conveyance distance	Good
Bassac River Upper right bank in Kandal Province	Svay Rolum District, Kandal Province	-	Better 31,500 m^3/day Difficult to take water over hundreds of thousands of m^3 per day	Water purification possible	Better Insufficient flow rate in the dry season	Close to new demand areas in the south	Additional purification treatment	-
	Setbou District	New Airport City				Close to the development site associated with the construction of the new airport	Additional purification treatment	Better
Prek Thnot River Southern part of Phnom Penh Capital	Boeng Thom District	-	Not good Demand for irrigation water is tight from the dry season to the beginning of the wet season.	Water purification possible	Not good Insufficient flow rate in the dry season	Relatively close to southern demand areas	-	Not good
Groundwater	Entire area of Phnom Penh Capital	-	Not good Many pumping wells required	Iron and arsenic concentration (partly)	Not good Limiting the amount of water taken from individual wells	Can be located only in the surrounding areas of Phnom Penh	Multiple wells need to be installed	Not good
Dam / Reservoir / Prek Thnot River Basin	Western region from Phnom Penh Capital	-	Not good Conditions for obtaining water rights allocation are not satisfied.	Good	Not good Not permitted	Remote area	long-distance water conveyance	Not good

CHAPTER 6 WATER PRODUCTION FACILITIES

6.1 EXISTING FACILITIES

6.1.1 Raw Water Intake Facilities

(1) Raw Water Intake Facilities for Phum Prek WTP

1) General

The Phum Prek WTP constructed in 1992 had an original production capacity of 56,000 m^3/day. The plant was expanded through the grant aid of Japanese Government by 44,000 m^3/day from 1993 to 1994 (Phase I) followed by another 50,000 m^3/day expansion from 2001 to 2003 (Phase II).

The pump units and complementary equipment were also renovated through the Phase II project of Japanese Grant Aid in which total production capacity reached 150,000 m^3/day in 2019. As of 2021, PPWSA remarks on its website that current production capacity has increased to 170,000 m^3/day.

The raw water intake tower of Phum Prek WTP is located in the Sap River near the Phnom Penh Port, 900 m downstream from Prek Pnov Bridge and 40 m away from the riverbank (see ***Figure 6.1.1***), having a truss bridge for access.

Figure 6.1.1 Location of Phum Prek Raw Water Intake Facilities
Source: JICA Data Collection Survey Team

The general plan of the raw water intake tower and its layout of the facilities are shown in ***Figure 6.1.2***.

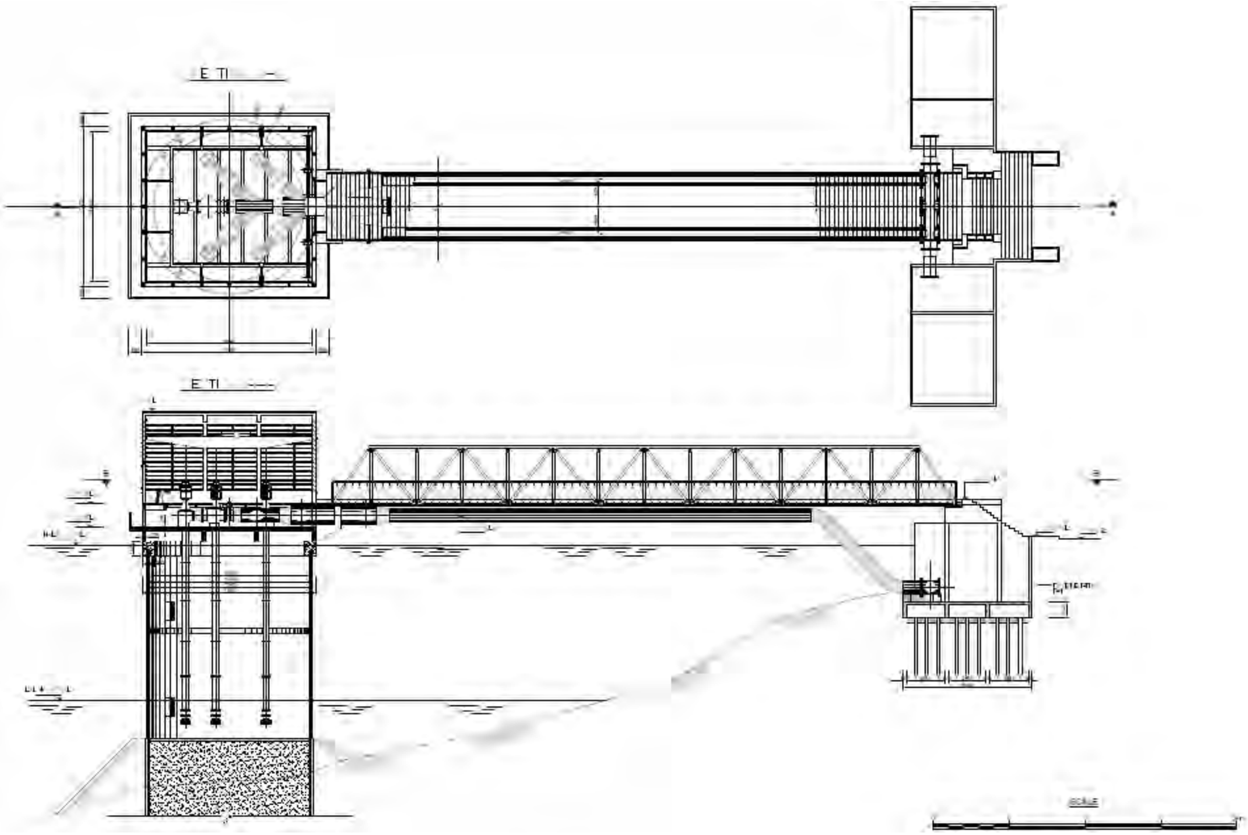


Figure 6.1.2 General Layout of Phum Prek Raw Water Intake Facilities
Source: PPWSA

Major equipment in the raw water intake facilities is summarized in ***Table 6.1.1***.

According to the design criteria in 2003, the projected intake rate was set at 158,400 m^3/day, including 5.6% daily production rate for operation and maintenance use.

Table 6.1.1 Major Components of the Phum Prek RawWater Intake Facilities

ITEMS	DESCRIPTION
Intake Type	Direct Intake Tower
Construction Year	Structure: 1966 Pump unit: 2003
Projected Intake Rate	158,400 m^3/day (including 5.6% daily maximum production)
Maximum Intake Rate	202,027 m^3/day (September 2019)
Water Level	HWL: +10.900 m AMSL, LWL: +1.580 m AMSL
Pump Type	Vertical Axial-Flow Pump
Suction pipe	Cast iron, Dia. 500 mm
Pumping Capacity	Q=2,200 m^3/hr as design rate [Pump data] Pump Rate: 35 m^3/min, Total Head: 25 m, Output: 210 kW Fly Wheel for water hammer protection
Number of Pump Unit	5 (4 for operation, 1 for stand by)
Intake Opening	4 (2 for HWL, 2 for LWL) with rectangular gate of manual operation
Dimension	Pump room: 10 m(L) x 11 m(W) x 8.7 m(H) Intake Pit: φ4.95 m x 11.6 m(Depth)
Accessories	Electric hoist crane (6 ton), Water level gauge
Other	Air vessel system is installed at the mail conduit line for protection of water hammer Ground level of intake point: +11.040 m AMSL

Source: Questionnaire for PPWSA, Basic design study report on the project for expansion of Phum Prek WTP in the Kingdom of Cambodia (Japan International Cooperation Agency: Tokyo Engineering Consultants Co., Ltd.: Nihon Suido Consultants Co., Ltd., 2001.1), Application document of Grant Aid from Japan for Rehabilitation of the Phum Prek WTP

2) Operating and Maintenance

According to the response from PPWSA to the questionnaire, the current status of operation and maintenance were confirmed as follows (see ***Table 6.1.2***).

Table 6.1.2 Operation and Maintenance Status of Phum Prek Raw Water Intake Facilities

ITEMS	DESCRIPTION
Operation Status	1. Number of constantly operating pumps: 5 in dry season, 4 in rainy season 2. Operation hours per day: 24 hours 3. Annual power consumption of raw water pump station: Monthly average 480,683 kWh, (Annual 5,768,200 kWh in 2019) ** The pumps installed in 2003 through Japanese Grant Aid are currently still in operation.*
Regulation of Intake Flow	There is a flow control valve of manual operation, but it remains full opened all the time.
Measuring Method	There is an electromagnetic flow meter of insertion type on the conduit pipe.
Influence by Low Water Level of River	Water intake has never been stopped due to a drop in river water level. Even at the lowest water level, the distance of 0.7 m or more is maintained between the impeller of the pump and the water level.
Electric Power	The pump may stop due to a power outage, but it does not occur frequently. Never lower allowable value has occurred.
Maintenance Work	The raw water pump is always staffed 24 hours a day and all equipment is checked by these staff visually. The mechanical equipment such as inside panel, vibration, temperature, etc. are inspected by the maintenance team once per week. The cleaning-up of pumping facilities is done once per month stopping its operation.

Source: Questionnaire for PPWSA

3) Problems and Issues to Be Solved, and Other Concerns

The points confirmed by the questionnaire and the hearing are as follows.

- The main structure of the current raw water intake tower was built in 1966 and 55 years have already passed. Due to the significant deterioration of the concrete and steel members of the inner wall, it is time to renew the structure.
- The building of the Ministry of Port and Communications was constructed over the main power supply line leading to the raw water intake tower. As of 2021 the deteriorated power supply lines remains running under the building, which is an obstacle to daily maintenance. However, this problem is going to be solved by construction of new power receiving facilities which is included in the components of new project for expansion of Phum Prek WTP scheduled after 2022.
- The water conduction pipes (φ700 mm x 2 lines) were laid at the same time as the construction of the raw water intake tower from 1965 to 1966. They are aging but are designated as backup lines because the water pipe was improved by the subsequent grant aid project.
- With the expansion of the Phum Prek WTP scheduled after 2022, the water conduction pipe with a diameter of 800 mm is going to be installed by PPWSA. This new line will be used for transmission of raw water with the projected rate of 45,000 m^3/day and the old conduction pipes will be decommissioned.

(2) Raw Water Intake Facilities for Chroy Changvar WTP

1) General

The Chroy Changvar WTP is the oldest plant in Phnom Penh. It was constructed in 1895 with a production capacity of 15,000 m^3/day. Through several renovations and expansions financially supported by World Bank in 2003 and 2009, the present production capacity has increased to 130,000 m^3/day. As of 2021, PPWSA remarks on its website that current production capacity has increased to 150,000 m^3/day.

The raw water intake tower of Chroy Changvar is located on the riverside of the upper Mekong, Sangkat Chroy Changvar 25 m away from the riverbank (see ***Figure 6.1.3***) and has a truss bridge for access. There are two towers, one of which was renovated in 2002 with four (4) motor pumps. The other was constructed in 2008 with 6 pumps.

The captured raw water is delivered to the WTP adjacent to the raw water intake tower and the treated water is transferred downtown across the Tonle Sap River through two pipelines (Dia.700 mm) attached to the Chroy Changvar No.1 Bridge, also known as the Cambodian-Japanese Friendship Bridge.

Figure 6.1.3 Location of Chroy Changvar Raw Water Intake Facilities
Source: JICA Data Collection Survey Team

The general plan of the raw water intake tower and its layout of the facilities are shown in ***Figure 6.1.4***.

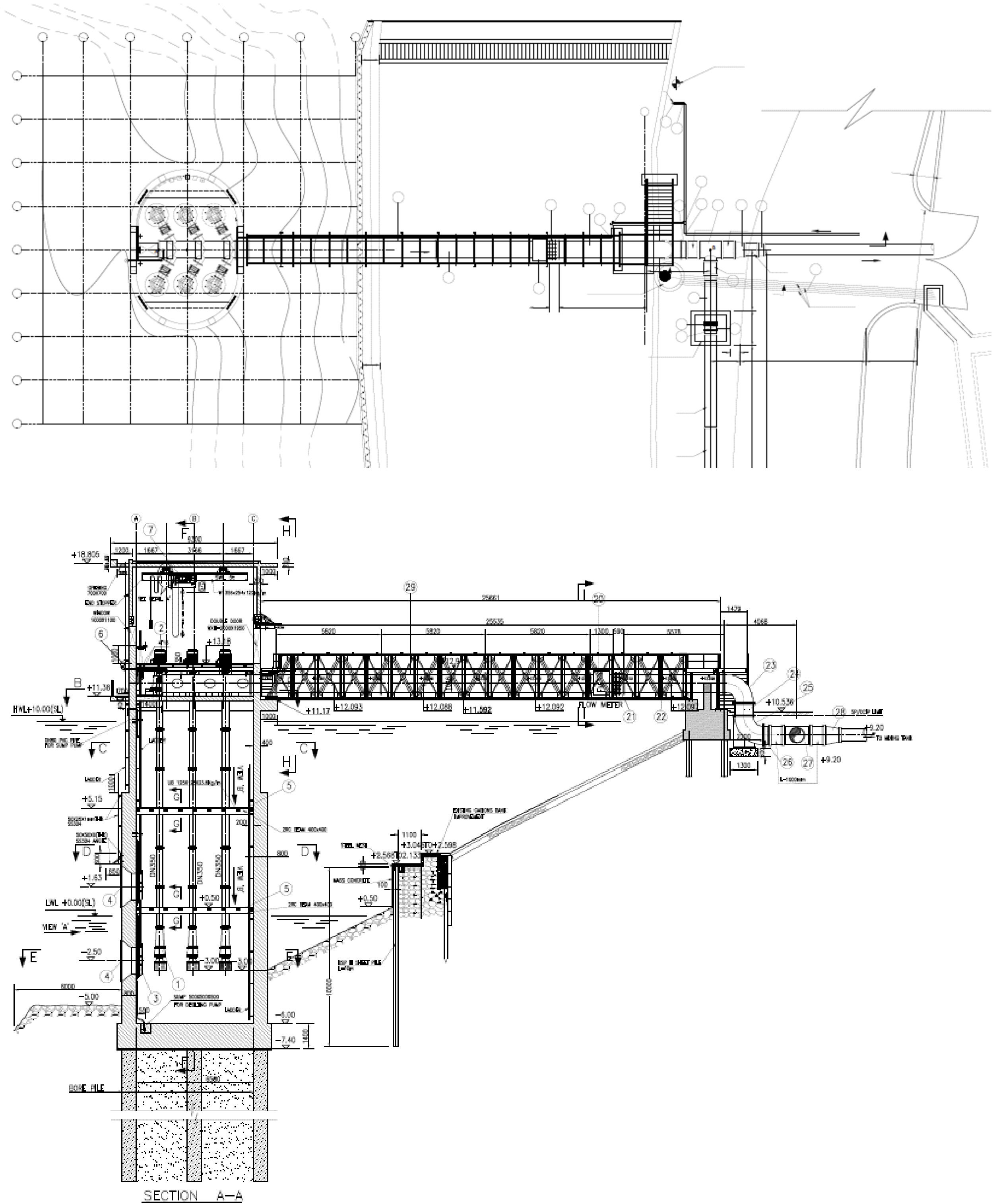


Figure 6.1.4 General Layout of Chroy Changvar Raw Water Intake Facilities
Source: PPWSA

Major equipment in the raw water intake facilities is summarized in ***Table 6.1.1***.

Table 6.1.3 Major Components of the Chroy Changvar Raw Water Intake Facilities

ITEMS	DESCRIPTION
Sutructure Type	Direct Intake Tower
Construction Year	Structure: 2003 & 2009 Pump unit: 2003 & 2009
Projected Intake Rate	150,000 m^3/day (actual capacity announced on PPWSA Web site) (No data about design rate of intake volume)
Maximum Intake Rate	193,900 m^3/day (May 2019)
Water Level	HWL: +10.000 m AMSL, LWL: +0.000 m AMSL
Pump Type	Vertical Axial-Flow Pump
Suction Pipe	Cast iron, Dia. 500 mm
Pumping Capacity & Number of Pump Unit	[Intake Tower 1] 75 kW each pump Number of pump unit: 4 (full operation without stand-by) [Intake Tower 2] 75 kW each pump Number of pump unit: 6 (full operation without stand-by) [Temporal pups in rainy season] 30kW, Q=300 m^3/hr, H=22 m Number of submersible pump unit: 3
Intake Opening	4 (2 at the level +2.50 m, 2 at the level +1.63 m) with rectangular gate of manual operation
Dimension	Pump room: 7 m(L) x 7 m(W) x 7.5 m(H) Intake Pit: φ9.5-φ6.5 m(Oval) x 17.4 m(Depth)
Accessories	Electric hoist crane (5 ton), Water level gauge
Other	Slab level of Intake House: +11.380 m AMSL

Source: Questionnaire for PPWSA, PPWSA Project Document (Extension of Phnom Penh Suburb Water Supply System, Expansion of Chroy Chang War WTP (Phase II)

2) Operating Condition

According to the response from PPWSA to the questionnaire, the current status of operation and maintenance were confirmed as follows (***Table 6.1.4***).

Table 6.1.4 Operation and Maintenance Status in Chroy Changvar Raw Water Intake Facilities

ITEMS	DESCRIPTION
Operation Status	3. Number of constantly operating pumps Dry season: 10 duty pumps Rainy season: 10 duty pumps and 3 additional stand-by pumps 2. Operation hours per day: 24 hours 3. Annual power consumption of raw water pump station: No data
Regulation of Intake Flow	The pump control panel has inverter system, and there is a control valve on the outlet line.
Measuring Method	[Pump installed in Phase I (2003)] Electromagnetic flowmeter on the wall of sedimentation basin [Pump installed in Phase II (2009)] Electromagnetic flowmeter on the access bridge and the wall of sedimentation basin
Influence by low water level of river	Raw water intake has never been stopped due to a drop in river water level. Even at the lowest water level, a distance of 1 m or more is maintained between the impeller of the pump and the water level.
Electrical Power	The pump may stop due to a power outage, but it does not occur frequently. Never lower allowable value has occurred.
Maintenance Work	The raw water pump is always staffed 24 hours a day and all equipment is checked by these staff visually. The mechanical equipment such as inside panel, vibration, temperature, etc. are inspected by the maintenance team once per week. The cleaning-up of pumping facilities is done once per month stopping its operation.

Source: Questionnaire for PPWSA

3) Problems and Issues to Be Solved, and Other Concerns

The points confirmed by the questionnaire and the hearing are as follows.

- The water quality analyzer was installed for the raw water intake tower of Phase I, but it was removed because it was not necessary for daily regular operation and monitoring work. No particular problems with operation management have been observed.

- The Intake tower of Phase II is under abnormal high ambient temperature. Solutions for this issue are under consideration.
- The river water level has gradually decreased and temporary pumps have been installed to secure adequate intake water when the water level drops significantly. There is an opinion from technical staff that the submersible pumps shall be used for stable capture of water when the decreasing tendency of water level continues. The idea will be adopted at the Bakheng WTP that is currently under construction (as of 2021) and submersible pumps will be used.
- The transformer was broken down due to over load in the past.

(3) Raw Water Intake Facilities for Nirodh WTP

1) General

The Nirodh WTP was constructed in two phases. The Phase I was constructed through cooperative loan by JICA and AfD in 2013. The Phase II plant was constructed in 2017 through an AfD independent loan.

The WTP has a total production capacity of 260,000 m^3/day. The raw water intake tower was constructed in Phase I with the AfD portion of the financial loan.

The raw water intake tower of Nirodh WTP is located on the river side of the lower Mekong River, extending two raw water suction pipes toward the river (see ***Figure 6.1.5***).

The captured water is delivered to the WTP located 2.6 km away from the intake point.

Figure 6.1.5 Location of Nirodh Raw Water Intake Facilities
Source: JICA Data Collection Survey Team

The general plan of the raw water intake site and layout of the facilities is shown in ***Table 6.1.6***.

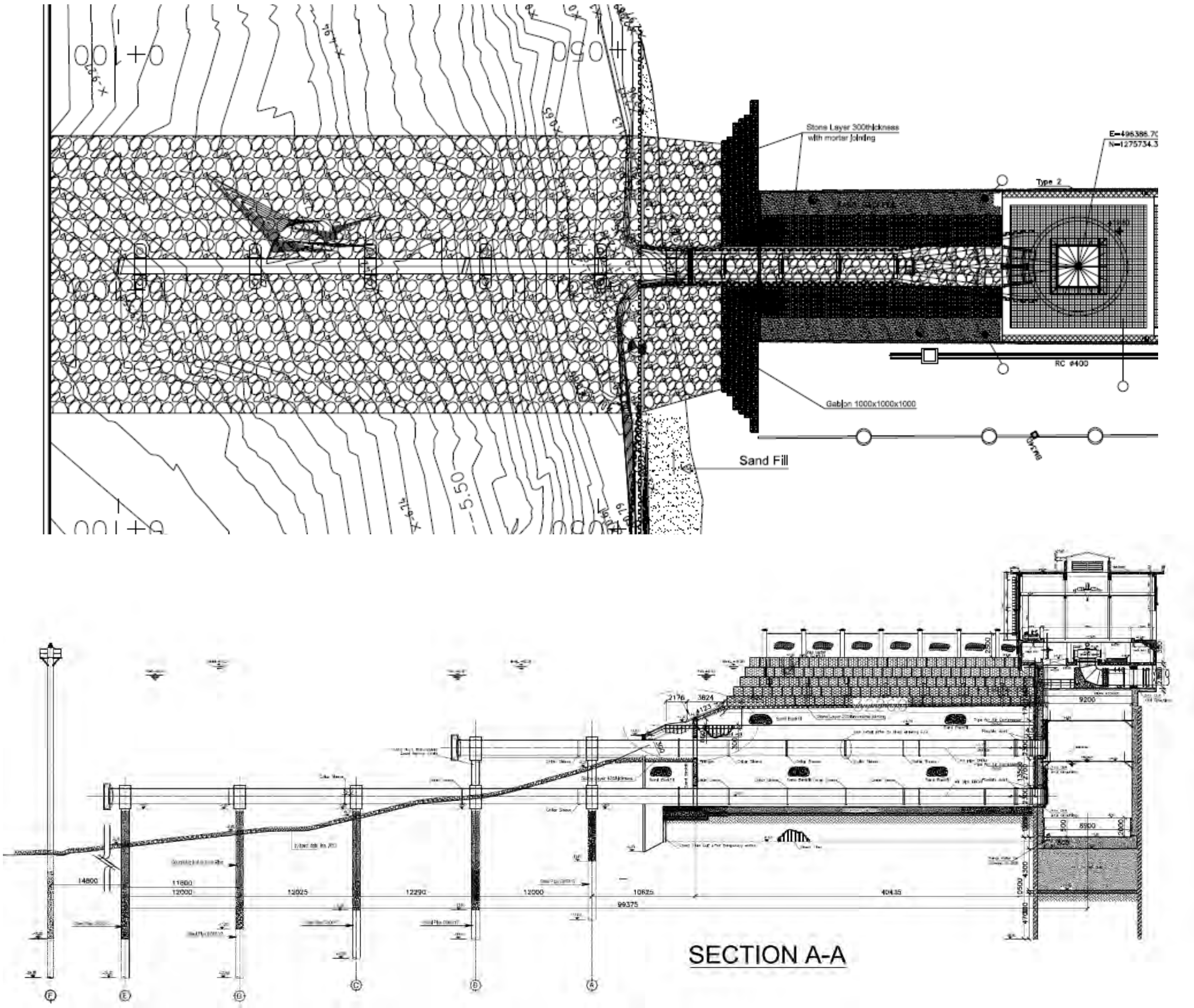


Figure 6.1.6 ***General Layout of Nirodh Raw Water Intake Facilities***
Source: PPWSA

Major equipment in the raw water intake facilities is summarized in ***Table 6.1.5***.

Table 6.1.5 ***Major components of the Nirodh Raw Water Intake Facilities***

ITEMS	DESCRIPTION
Sutructure Type	Tower with Extended Intake Pipe
Construction Year	Structure: 2013 Pump unit: 2013 (Phase I) & 2017 (Phase II)
Projected Intake Rate	270,000 m^3/day (Phase I: 135,000 m^3/day, Phase II: 135,000 m^3/day)
Maximum Intake Rate	316,230 m^3/day (September 2019)
Water Level	HWL: +9.200 m AMSL, LWL: +0.500 m AMSL
Pump Type	Vertical Axial-Flow Pump
Suction Pipe	Ductile Cast Iron, Dia.500 mm
Pumping Capacity	Q=2,200m^3/hr, H=17m, Output:160 kW
Number of Pump Unit	8 (6 for operation, 2 for stand by as design condition)
Intake Opening	2 with rectangular gate of electric motor operation (1 for high level, 1 for low level) Diameter of intake pipe: DN1600
Dimension	Pump room: 12 m(L) x 12 m(W) x 9.3 m(H) Intake Pit: φ9.2 m x 13.5 m(Depth)
Accessories	Electric hoist crane (6 ton), Water level gauge
Other	Slab base level of pump room: +10.500 m AMSL Conduit pipe: DI DN1600

Source: Questionnaire for PPWSA and PPWSA Project Document (Nirodh Production Facilities Phase I, Phase II)

2) Operating Condition

According to the questionnaire, the operation and maintenance status of the current raw water intake facility were confirmed as follows (***Table 6.1.6***).

Table 6.1.6 Operation and Maintenance Status in Nirodh Raw Water Intake Facilities

ITEMS	DESCRIPTION
Operation Status	1. Number of constantly operating pumps: 8 units 2. Operation hours per day: 24 hours 3. Annual power consumption of raw water pump station: Monthly average 923,345kWh (Annual average 11,080,147 kWh in 2019)
Regulation of Intake Flow	The pump control panel has inverter system, and there is a control valve on the outlet line. The pump can be controlled through remote operating system from WTP.
Measuring Method	Measurement by an electromagnetic flow meter installed in the WTP
Influence by low water level of river	Raw water intake has never been stopped due to a drop in river water level.
Electrical Power	Never lower allowable value has occurred.
Maintenance Work	The water raw water pump is always staffed 24 hours a day and all equipment is checked by these staff visually. The mechanical equipment such as inside panel, vibration, temperature, etc. are inspected by the maintenance team once per week. The cleaning-up of pumping facilities is done once per month stopping its operation.

Source: Questionnaire for PPWSA

3) Problems and Issues to Be Solved, and Other Concerns

A large-scale land reclamation project is underway on the riverbank where the current raw water intake tower is located and the existing intake facility needs to be relocated (see ***Table 6.1.7***). According to the negotiations between PPWSA and the business planner, they already agreed that the private reclamation company secure land and relocation cost of existing water intake facilities. Securing the construction cost of the intake facility for new expansion remains an issue.

Figure 6.1.7 General Layout of Nirodh Raw Water Intake Facilities
Source: PPWSA

In addition, the accumulation of shellfish in the raw water intake pipe of Nirodh causes obstruction of water flow. Many years have passed since construction and the shellfish accumulation is now quite serious.

The occurrence of shellfish is normally related to plankton and nutrients in the water quality but the exact cause is unknown at this time. Although shellfish are found in other intake facilities in Phnom Penh, there is no significant influence in the case of the intake tower type.

The intake point near the existing Nirodh raw water intake is below the confluence with the Bassac River, and the development status of the surrounding area and the inflow of domestic wastewater may be a factor in this phenomenon. In this case, it is necessary to consider measures such as chlorine injection at the water intake in the future.

(4) Raw Water Intake Facilities for Chamcar Mon WTP

1) General

The Chamcar Mon WTP is the second oldest plant in Phnom Penh. It was constructed in 1958 with an original production capacity of 10,000 m^3/day. Through several renovations and expansions financially supported by AfD, the present production capacity has increased to 52,000 m^3/day. As of 2021, PPWSA remarks on its website that the actual capacity has increased to 54,000 m^3/day.

The intake tower of Chamcar Mon is located in the Bassac River, extending two raw water suction pipes toward the river, similar to the Nirodh WTP (see ***Figure 6.1.8***). This raw water intake tower was recently constructed in 2019 under expansion of the treatment plant through a joint investment fund set up by AfD and PPWSA.

The Chamcar Mon WTP adopts a modular water treatment process that is more complicated to operate and more difficult to maintain water quality than in other WTPs in the city. A total of eight (8) small filters require laborious daily washing. Operators are facing difficulties with proper operation and satisfactory maintenance.

Figure 6.1.8 Location of Chamcar Mon Intake Facilities
Source: JICA Data Collection Survey Team

The general plan of the raw water intake site and layout of the facilities is shown in ***Figure 6.1.9***.

This raw water intake tower is a new facility that started operation in 2019 and the following measures to facilitate operation management are reflected in the design:

- The inside of the raw water intake tower is divided into two basins by the central wall, and two pumps are installed for each.

- A space for sedimentation is independently secured on the river side inside the raw water intake tower, and a submersible pump for sludge is permanently installed.

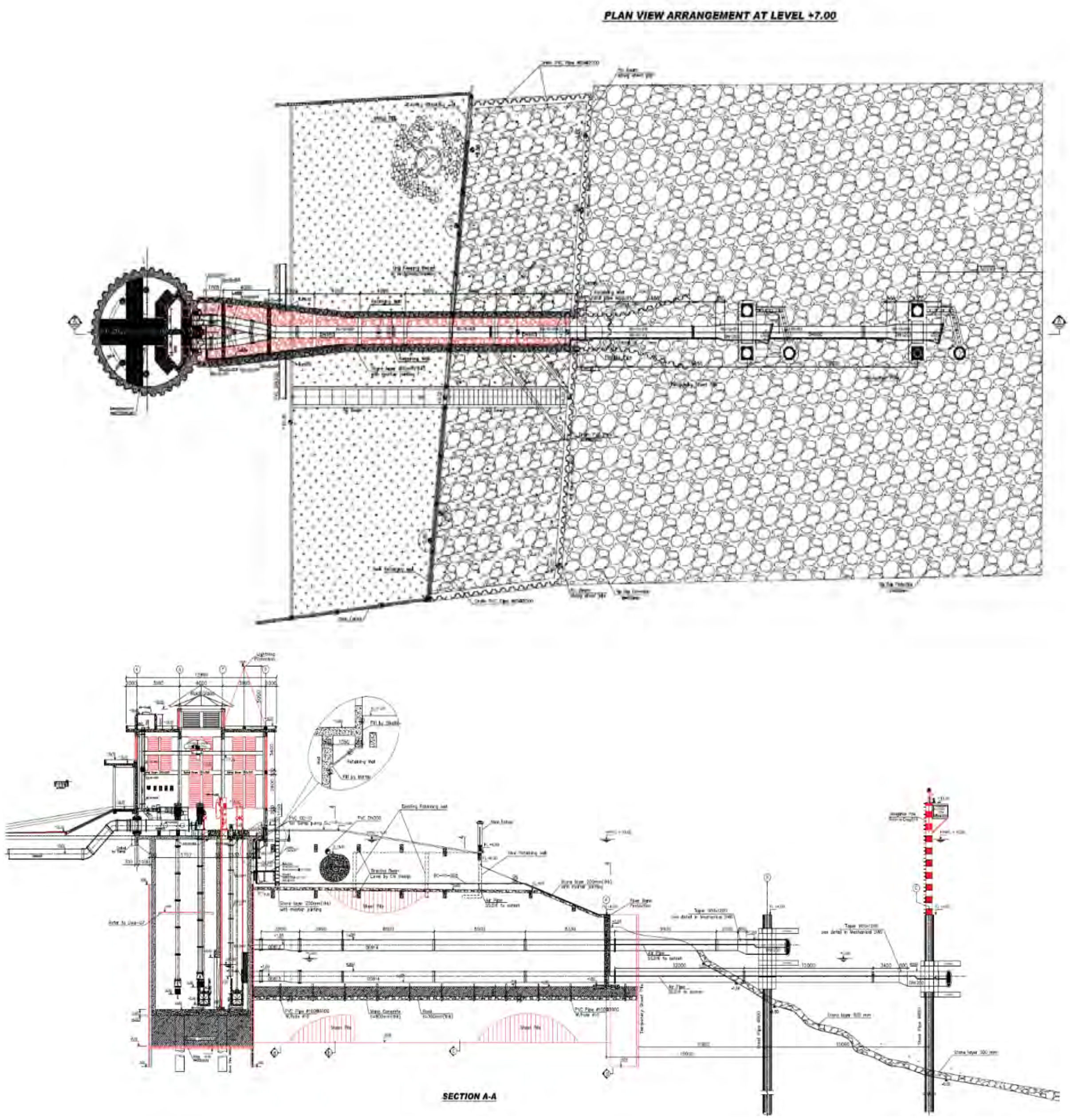


Figure 6.1.9 General Layout of Chamcar Mon Raw Water Raw Water Intake Facilities
Source: PPWSA Project Document

Major equipment in the raw water intake facilities are summarized in ***Table 6.1.7*** .

Table 6.1.7 Major components of the Chamcar Mon Raw Water Intake Facilities

ITEMS	DESCRIPTION
Sutructure Type	Tower with Extended Intake Pipe
Construction Year	2019
Projected Flow Rate	52,000 m^3/day (as actual production capacity)
Water Level	HHWL: +10.200 m AMSL, LWL: -0.070 m AMSL
Pump Type	Vertical Axial-Flow Pump
Suction Pipe	Ductile Cast Iron, Dia. 500 mm
Pumping Capacity	Q=794 m^3/hr, Output:75 kW
Number of Pump Unit	4 (3 for operation, 1 for stand by)
Intake Opening	2 with rectangular gate, Diameter:DN800
Accessories	Electric hoist crane (4 ton), Water level gauge

ITEMS	DESCRIPTION
Other	Slab base level of pump room: +10.500 m AMSL Conduit pipe: DI DN800 mm

Source: PPWSA

2) Operating Condition

Average total power and fuel consumption are summarized in ***Table 6.1.8***. In addition, the time of verification (2020) is within the defect warranty period and minor defects are dealt with by the contractor.

Table 6.1.8 Operation and Maintenance Status in Chamcar Mon Raw Water Intake Facilities

ITEMS	DESCRIPTION
Operation Status	1. Number of constantly operating pumps: 2 units 2. Operation hours per day: 24 hours 3. Power consumption of raw water pump station: Monthly average 117,414 kWh, (Annual 1,408,971 kWh in 2020)
Regulation of Intake Flow	The pump control panel has inverter system, and there is a control valve on the outlet line. The pump can be controlled through remote operating system from WTP.
Measuring Method	Measurement by an electromagnetic flow meter installed in the western side of intake well
Influence by low water level of river	Water intake has never been stopped due to a drop in river water level.
Electrical Power	Never lower allowable value has occurred.
Maintenance Work	The raw water pump is always staffed 24 hours a day and all equipment is checked by these staff visually. The mechanical equipment such as inside panel, vibration, temperature, etc. are inspected by the maintenance team once per week. The cleaning-up of pumping facilities is done once per month stopping its operation.

Source: Questionnaire for PPWSA

3) Problems and Issues to Be Solved, and Other Concerns

The Chamcar Mon intake facility was recently renewed in 2019 and there are no major problems with its current operation.

However, since the raw water intake pipe similar to that of Nirodh is adopted for Chamcar Mon, it may be necessary to consider measures such as chlorine injection at the water intake if shellfish start accumulating in the pipe.

6.1.2 Raw Water Transmission Mains and WTPs

(1) General

The existing WTPs are summarized in ***Table 6.1.9***.

Table 6.1.9 Existing WTPs

WTP	PHASE	COMPLETION	DESIGN CAPACITY	TREATMENT METHOD	CONDITIONS
Phum Prek	Phase I	1965/88/95	100,000 m^3/d	Coagulation/ Sedimentation/ Filtration	Aged and deteriorated
	Phase II	2003	50,000 m^3/d		Partially aged and deteriorated
Chroy Changvar	Phase I	2002	65,000 m^3/d		Partially aged and deteriorated
	Phase II	2009	65,000 m^3/d		Good
Nirodh	Phase I	2013	52,000 m^3/d		Good
	Phase II	2016	130,000 m^3/d		Good
Chamcar Mon	---	2019	130,000 m^3/d		New and good
Total			592,000 m^3/d		

Source: JICA Data Collection Survey Team based on data provided by PPWSA

The amount of water consumed in the PPWSA water supply area is increasing year by year, and WTPs have been constructed accordingly. With the construction of WTPs, the amount of water treated at each plant and the amount of water treated in PPWSA have fluctuated significantly. WTPs in PPWSA are increasing the amount of treated water year by year. ***Figure 6.1.10*** summarized this trend from 2010 to 2020. During this period, the Nirodh treatment plants Phase I and Phase II went into operation and the Chamcar Mon treatment plant was rebuilt.

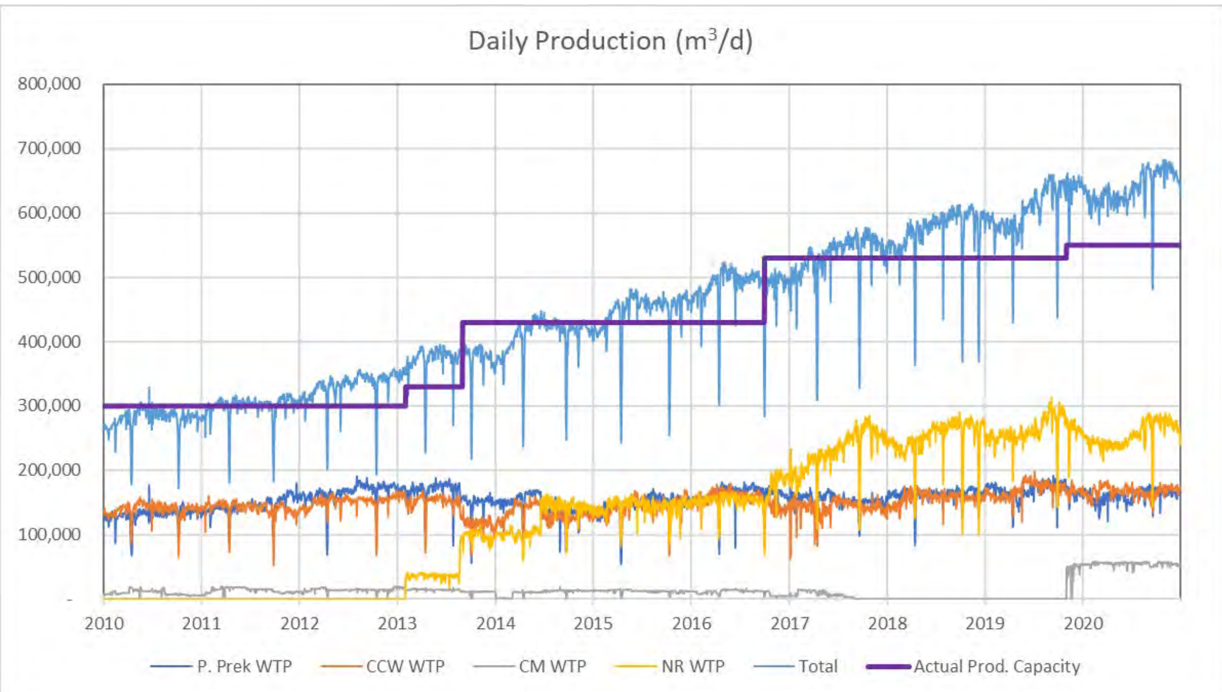


Figure 6.1.10 Daily production (2010-2020)

Source: JICA Data Collection Survey Team based on data provided by PPWSA

Daily average production in 2010 and 2020 are shown in ***Table 6.1.10***. It indicates significant increase in water production capacity during this decade.

Table 6.1.10 Treated Water Production in 2010/2020 (Daily Average)

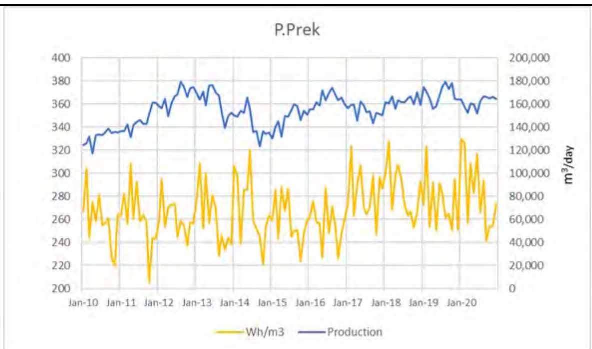
WATER PRODUCTION	PHUM PREK (P. Prek)	CHROY CHANGVAR (CCW)	CHAMCAR MON (CM)	NIRODH (NR)	TOTAL
2010 (m^3/d, daily average)	131,576	138.976	9,571	0	280,078
2020 (m^3/d, daily average)	160,909 (25.2%)	167,494 (26.3%)	54,897 (8.6%)	254,460 (39.9%)	637,761 (100%)
Increase ratio	22.3%	20.5%	473.6%	---	127.7%

Source: JICA Data Collection Survey Team based on data provided by PPWSA

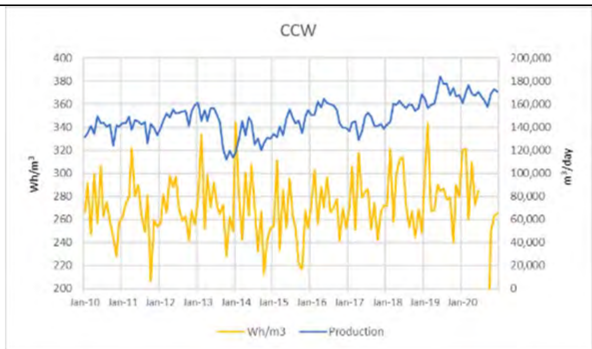
Total water production in 2010 and 2020 increased by 127.7%. Since the operation of newly constructed Nirodh Phase I and Phase II plants contribute about 40% of the production and Chamcar Mon WTP resumed in January 2020. The amount of water produced by other WTPs has increased by about 25% by overloaded operating condition.

1) Energy Efficiency

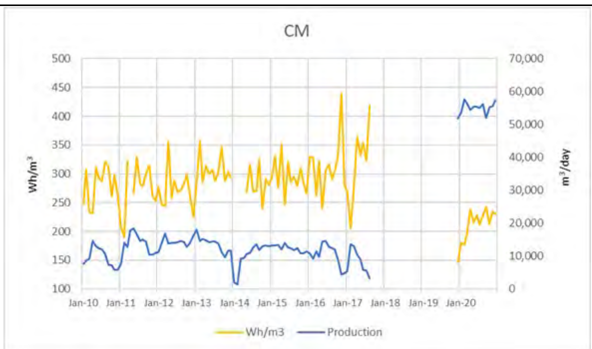
Figure 6.1.11 and ***Figure 6.1.12*** show the amount of treated water from the four PPWSA treatment plants from 2010 to 2020 and the amount of electricity used per 1 m^3 of water produced. It can be seen that the amount of treated water fluctuates according to water demand and season. On the other hand, fluctuation of the amount of electricity used is more dependent on the season than the amount of water treated.



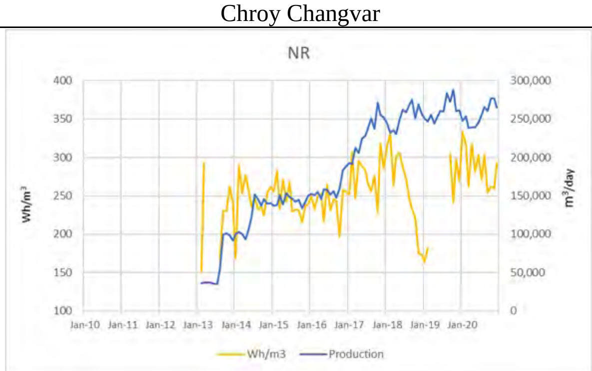
Phum Prek



Chroy Changvar



Chamcar Mon



Nirodh

Figure 6.1.11 Daily production in Each WTP (2010-2020)

Source: JICA Data Collection Survey Team based on data provided by PPWSA

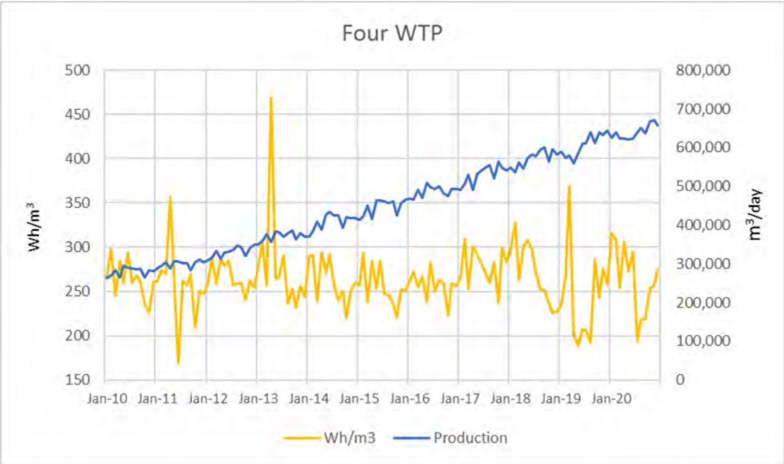


Figure 6.1.12 Daily production in Four WTPs (2010-2020)
Source: JICA Data Collection Survey Team based on data provided by PPWSA

PPWSA's water production has shown constant growth over the last decade in response to growing water demand. The production at Phum Prek WTP and Chroy Changvar WTP has been gradually increasing according to water demand, but the production volume of Chamcar Mon WTP has increased significantly since its construction in 2020. In addition, the construction of Phase I and Phase II of the Nirodh WTP has been completed, and the amount of water production has been increased step by step.

Table 6.1.11 Unit Electricity Consumption in 2020

WTP	P.Prek	CCW	CM	NR	AVERAGE
Electricity (kWh/m^3)	0.270	0.279	0.227	0.285	0.275

Source: JICA Data Collection Survey Team based on data provided by PPWSA

From ***Table 6.1.11*** above, it can be seen that the Chamcar Mon WTP consumes the least amount of electricity for producing and distributing 1 m^3 of finished water.

With the exception of the Chroy Changvar WTP, the water intake station and the WTP have separate power supply systems. The power consumption of the water intake station and the WTP are measured separately. The following ***Figure 6.1.13*** shows the annual power consumption in 2020.

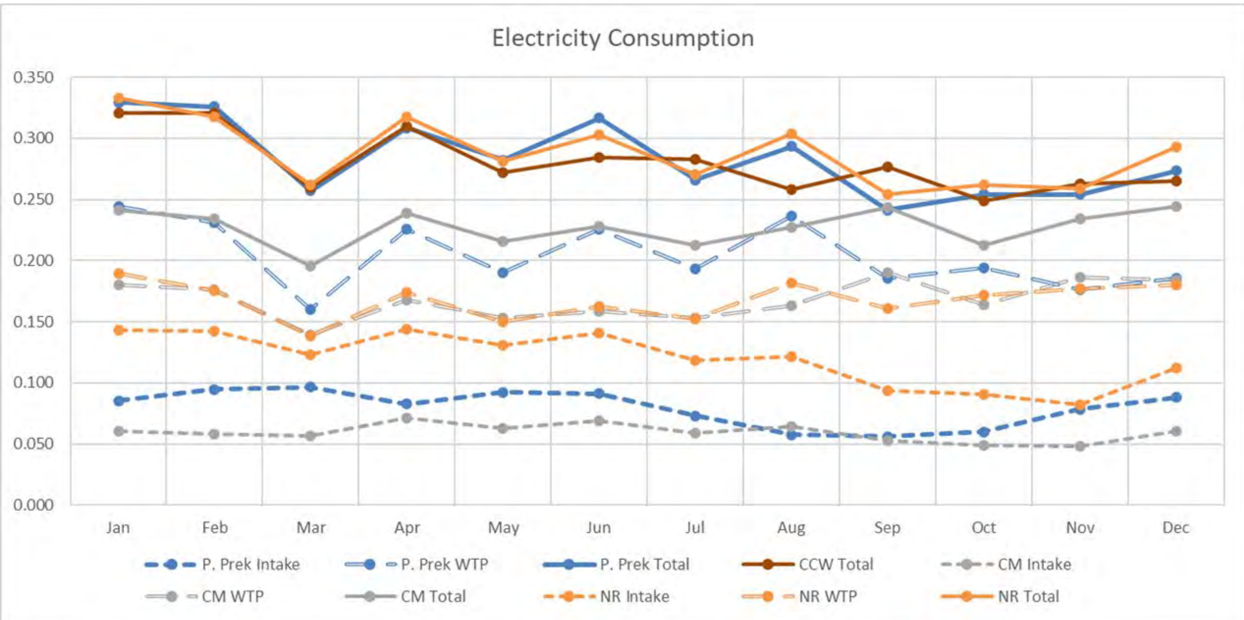


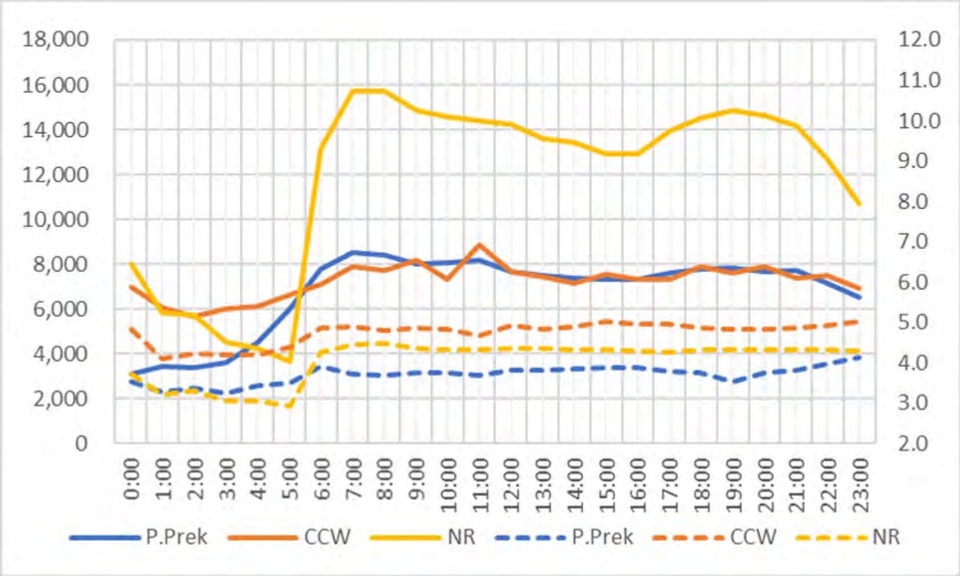
Figure 6.1.13 Energy Consumption of Each Treatment Plants (2020)
Source: JICA Data Collection Survey Team based on data provided by PPWSA

Most of the electricity used in the water systems is for the operation of intake and distribution pumps.

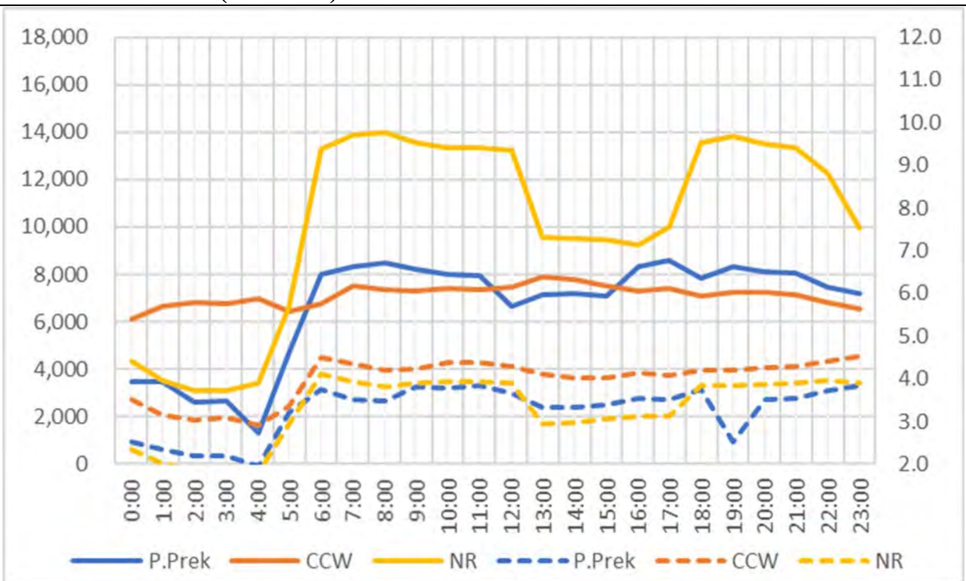
Figure 6.1.13 shows the total electricity consumption of the four WTPs in 2000. The total of water intake and WTP is about 0.3 Wh/m^3. It consists of a water intake of 0.1 kWh/m^3 and a WTP of 0.2 kWh/m^3. Electricity consumption for intaking water from August to October is about half that of other months. This is because the river water level of the river rises.

As mentioned above, the Chamcar Mon WTP uses overwhelmingly less electricity than the other three WTPs. This means that the amount of electricity used at the water intake is small, and the amount of electricity used at the WTP is also small. This is because the water intake and the WTP are relatively close to each other and the amount of electricity used is low. Furthermore, variable speed control has been adopted in the water distribution pump equipment to achieve efficient operation of the water distribution pump.

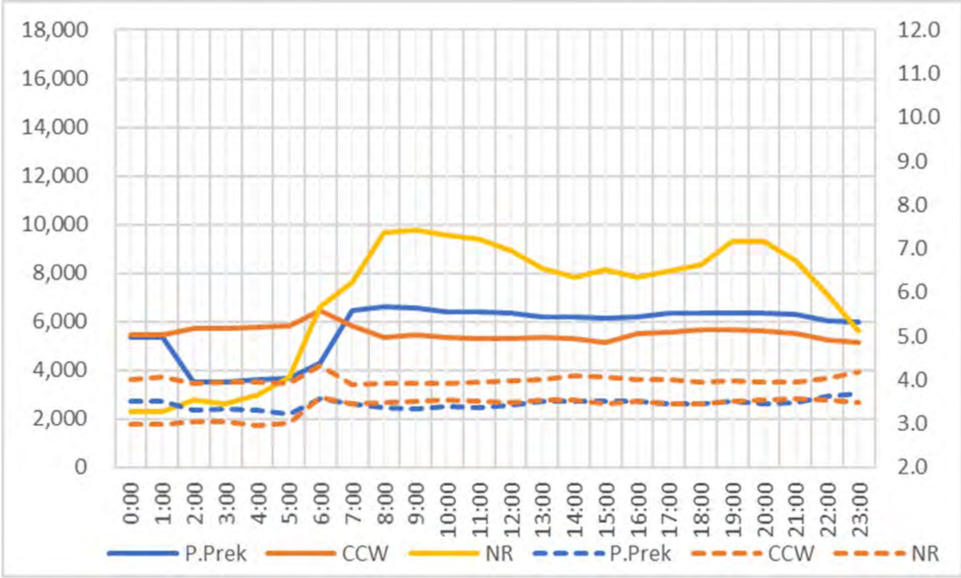
On the other hand, the Chroy Changvar WTP is very close to the intake point from the Mekong River, but this does not reflect its superiority compared to other WTPs. The reason for this is that the main water distribution point is across the Sap River to the center of Phnom Penh, which consumes a lot of energy for water delivery. In the future, water demand is expected to increase in the area around the WTP, and the energy consumption per m^3 required for water delivery is also expected to decrease as the relative volume of water delivered to the city center decreases.



Maximum Production (Oct 27 ‘20)



Median Production (Jun 4 ‘20)



Minimum Production (Sep 18 '20)

Figure 6.1.14 Water Distribution Flow and Pressure of Each WTP (2020)

Source: JICA Data Collection Survey Team based on data provided by PPWSA

Hourly distribution flow and distribution pressure from the WTPs for maximum distribution day (October 27), median distribution day (June 4) and minimum distribution day (September 18) in 2020 and the operation status of 3 WTPs excluding the Chamcar Mon WTP are summarized in ***Figure 6.1.14***. On the maximum and median days, the Phum Prek WTP and the Chroy Changvar WTP supply water at approximately 8,000 m^3/hr, except during the early morning. The water distribution pressure is about 3.5 bar. On the other hand, the Nirodh WTP contributes most to the adjustment of water distribution. It clearly shows the time variation pattern of water distribution. In addition, the water distribution pressure is high due to distance from the demand area, so a high pressure of 5-6 bar is required to distribute water.

2) Treatment Performance

Figure 6.1.15 shows the turbidity of raw and treated water from WTPs in 2010-2020. When the turbidity of raw water increases, the quality of treated water deteriorates, but turbidity generally maintained below 1 NTU. The Chamcar Mon WTP exceeded 3 NTU in treated water several times before reconstruction but turbidity has remained well below 1 NTU after the new facility was completed.

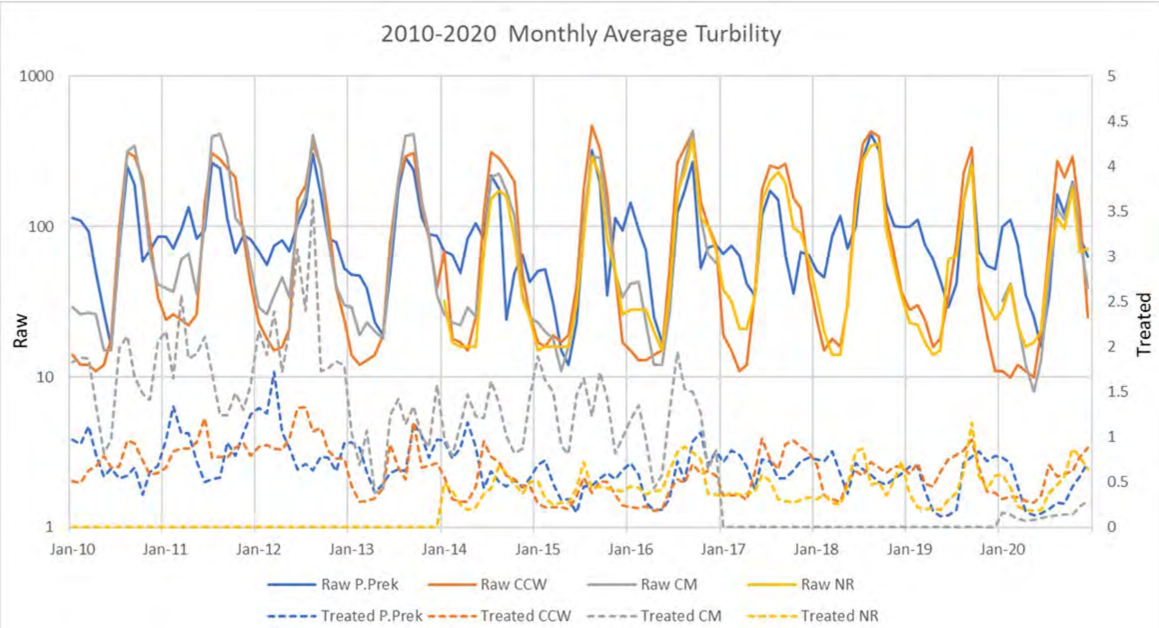


Figure 6.1.15 Raw Water/Teated Water Turbidity in Each WTP (2010-2020)

Source: JICA Data Collection Survey Team based on data provided by PPWSA

Raw water for all four WTPs originally flows from the upstream of the Mekong River. The water level of the river rises due to the rainfall upstream and the turbidity increases. Turbidity is over 100 NTU for all four WTPs from June to October every year. Turbidity is particularly high from July to September when the average monthly turbidity is close to 500 NTU. Another characteristic is the raw water from the Phum Prek WTP. In addition to the high turbidity between June and October, the turbidity rises to nearly 100 NTU every year from December to February. This is because the water pushed up by the Sap River between June and October flows down with high turbidity as the water level of the Mekong River drops. A part of this flowing water also mixes with the raw water of the Chamcar Mon WTP and Nirodh WTP located on the west bank of the downstream of the Mekong River.

It was confirmed that the WTPs are able to adapt to these changes in raw water quality and maintain satisfactory removal of turbidity. ***Figure 6.1.16*** shows the turbidity of each water treatment process at the highest turbidity, average turbidity, medium turbidity, and lowest turbidity of raw water in 2020 at four WTPs.

Chroy Changvar WTP, which intakes water directly from the Mekong River, has recorded a maximum turbidity of 875 NTU, and other WTPs have also recorded approximately 500 NTU. On the other hand, the minimum turbidity is 3.7 to 6.79 NTU, which shows that there is a large fluctuation in one year. In any case, a jar test is conducted every day to confirm the optimum dosing rate of the flocculant PAC, and the injection is properly performed. Even at this high turbidity, the settled water maintains about 5 NTU, and the filtered water is less than 1.0 NTU. From this point, it can be judged that all four WTPs are operating well.

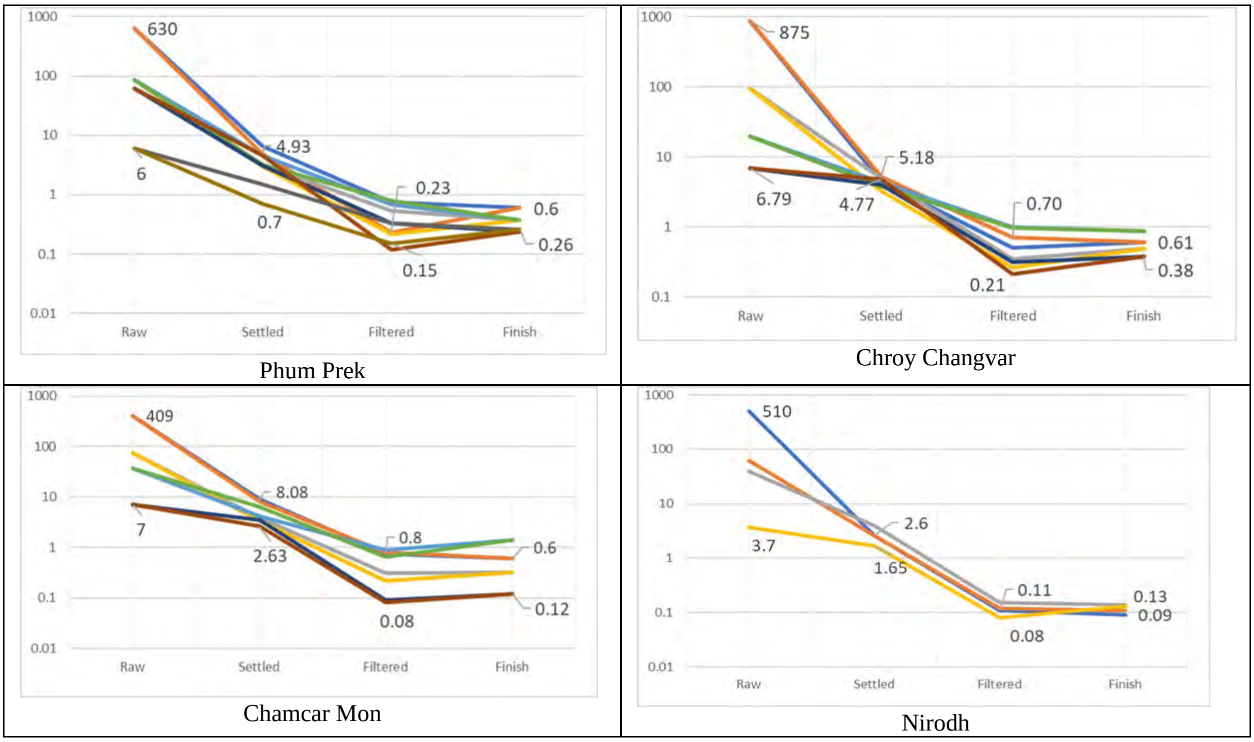


Figure 6.1.16 Turbidity at Each Treatment Process (2020)
Source: JICA Data Collection Survey Team based on data provided by PPWSA

3) Chemical Consumption

Alum was used as coagulant and lime for pH adjustment until 2012. After 2013, all WTPs switched to PAC and pH adjustment became unnecessary. Lime has not been used since. Generally, chlorine gas is used for disinfection. In 2016 Phum Prek WTP started manufacturing its own a sodium hypochlorite on-site using electrolysis. PPWSA plans to sequentially switch other WTPs to on-site sodium hypochlorite generation. The amount of chemicals used depend on the pollution load of the water source.

Table 6.1.12 shows usage per unit treated water of PAC and chlorine or NaOCl (from Salt) at each WTP.

Table 6.1.12 Unit Chemical and Electricity Consumption in 2020

WTP	P.Prek	CCW	CM	NR	TOTAL/AVERAGE
Production (m^3)	58,892,848	61,302,890	20,092,388	93,132,313	233,619,630 (Total)
PAC (g/m^3)	9.79	6.07	10.75	8.42	8.36 (Average)
Chlorine (g/m^3)	0.54	1.24	0.00	2.46	1.97 (Average)
Salt (g/m^3)	10.93	5.59	9.11	0.00	8.33 (Average)
NaOCl (g/m^3)	2.30	1.00	3.14	0.00	1.85 (Average)

Source: JICA Data Collection Survey Team based on data provided by PPWSA

Lower dosage of the chemicals is required for the plants using Mekong River as the water source.

4) Operation Cost

From 2019 operation records of four WTPs, except Chamcar Mon for November 2019 to May 2020, cost for electricity and chemicals per m3 treated water is calculated in ***Table 6.1.13***. About 80% of these costs is for electricity.

Table 6.1.13 Unit Chemical/Electricity Consumption and Cost in 2020

WTP		P.Prek	CCW	CM	NR	Average
PAC	(g/m^3)	9.79	6.07	10.75	8.42	8.36
	3.29 R/g	32.21	19.97	35.37	27.70	27.50
Chlorine	(g/m^3)	0.54	1.24	0.00	2.46	1.97
	8.04 R/g	4.34	9.97	0.00	19.78	15.84
Salt	(g/m^3)	10.93	5.59	9.11	0.00	8.33
	0.88 R/g	8.46	4.92	8.02	0.00	7.33
(NaOCl)	(g/m^3)	2.30	1.00	3.14	0.00	1.85
Electricity	(kWh/m^3)	0.270	0.279	0.227	0.285	0.275
	588 R/kWh	150.66	155.68	126.67	159.03	153.45
Total (R/m^3)		(R/m^3)	190.54	170.06	206.51	204.12

Source: JICA Data Collection Survey Team based on data provided by PPWSA

The amount of electricity is the most important index from the cost incurred, and it is the most important item to consider when seeking to reduce operating costs.

On the other hand, since the amount of chemicals consumed depends on raw water quality, the amount of chemicals used (especially PAC) can be used to judge the quality of raw water. From this point of view, it can be judged that water treatment at both Chroy Changvar and Nirodh WTPs, which take raw water from the Mekong River, is relatively simple.

(2) Phum Prek WTP

1) Raw Water Transmission Mains

The general overview of the raw water intake, raw water transmission mains, and WTP are shown in ***Figure 6.1.17*** and ***Figure 6.1.18*** below.

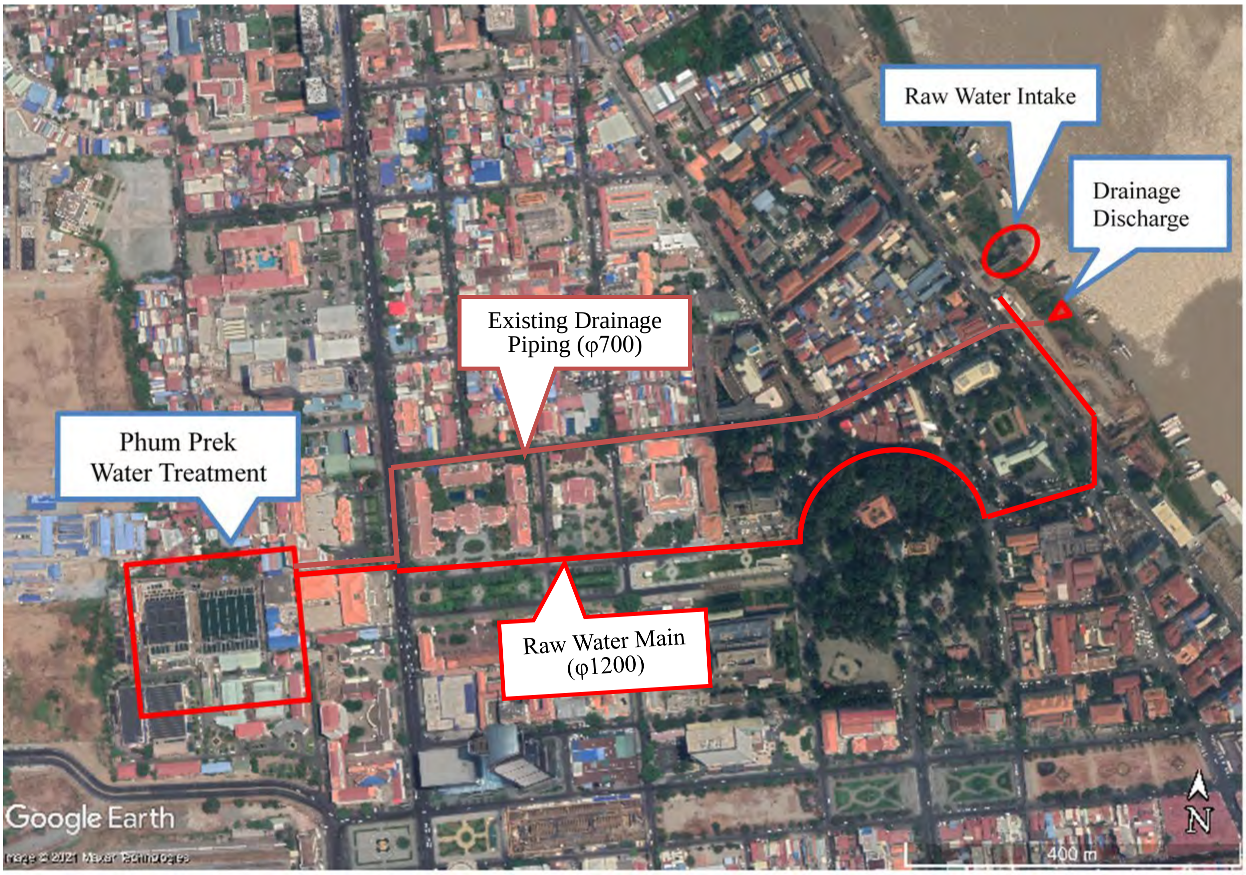


Figure 6.1.17 General Overview of the Raw Water Transmission Mains
Source: PPWSA

A 1200 mm diameter ductile cast iron water transmission main and power supply cable were installed in 2003. The existing raw water transmission mains (700 mm diameter cast iron pipes) were installed in 1958 and 1966. After installation of the 1200 mm diameter main, the two 700 mm mains have been designated as stand-by mains.

Raw water transmission main was installed in the following conditions ***(Table 6.1.14)***.

Table 6.1.14 General Profile of the Raw Water Transmission Mains

LOCATION	DISTANCE (m)	GROUND LEVEL (m AMSL)	PIPE CROWN LEVEL (m AMSL)	EARTH COVERING (m)
Near Intake Station	0	+11.040	+9.340	+1.700
Inside of WTP	1,500	+12,500	+11.961	+0.539

Source: JICA Data Collection Survey Team based on data provided by PPWSA

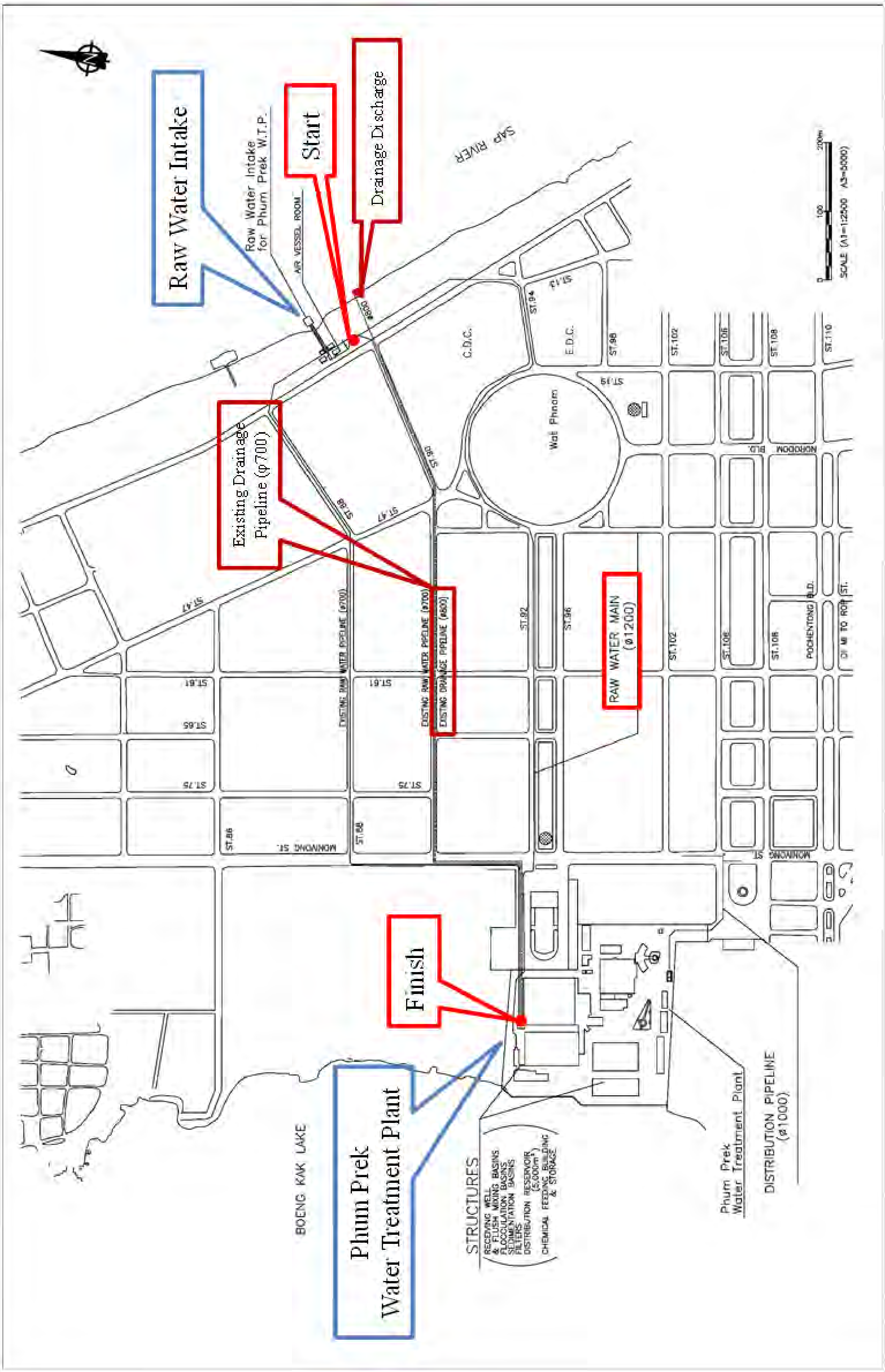


Figure 6.1.18 Phum Prek - General Overview of the Raw Water Transmission Mains
Source: PPWSA

2) Water Treatment Plant

a. General

The general plan of the water treatment site and layout of the facilities is shown in ***Figure 6.1.19***.

Phum Prek WTP was constructed in two stages. The old plant with a production capacity of 100,000 m^3/day was constructed in 1965 and was rehabilitated in 1988 and 1995. New treatment facilities with additional production capacity of 50,000 m^3/day were constructed in 2003.

The process diagram and hydraulic profile of the water treatment are shown in ***Figure 6.1.20***.

Major equipment in the raw water intake facilities is summarized in ***Table 6.1.14***.

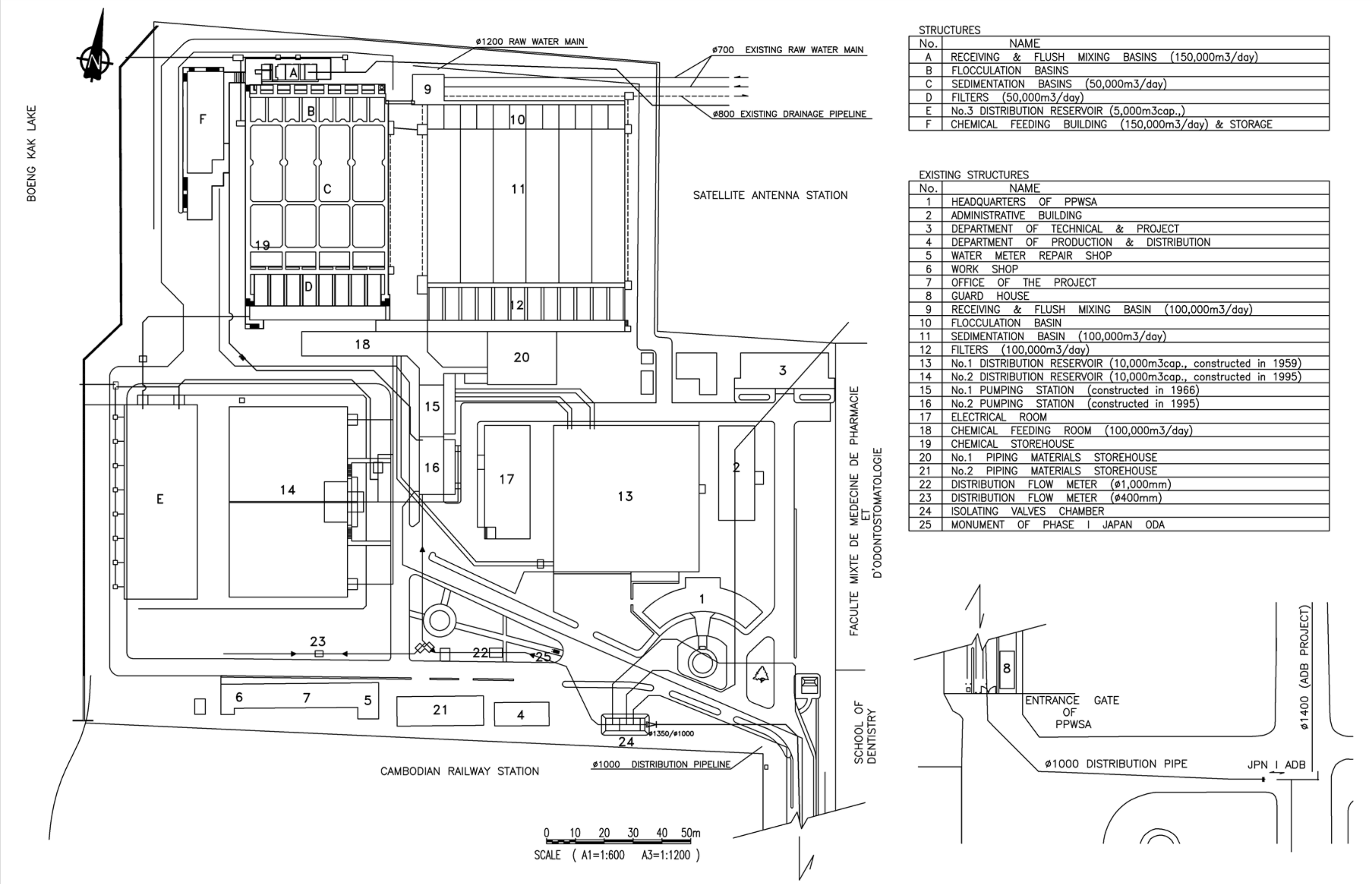


Figure 6.1.19 General Plan of the Water Treatment Site and Layout of the Facilities

Source: PPWS

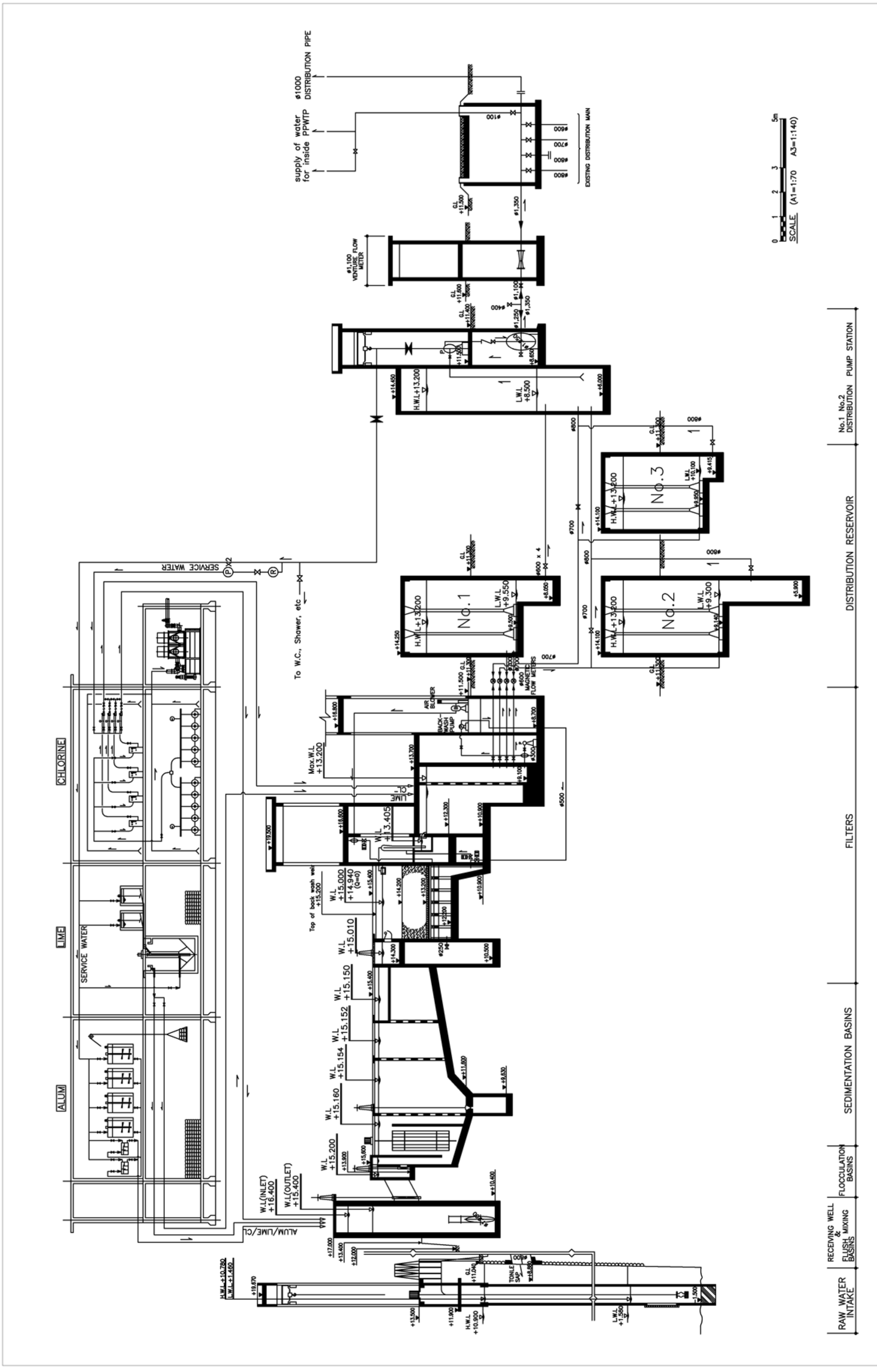


Figure 6.1.20 Water Treatment Process
Source: PPWSA

Table 6.1.15 Phum Prek - Major Facilities and Equipment of the Raw Water Intake Facilities

Capacity		100,000	m^3/d	(Old)		50,000 m^3/d	(New)		
Water Source		158,400	m^3/d	Tonle Sap		HWL = 10.9 m, LWL = 1.5m			
Construction		1965	costruction of old plant						
		1988, 1995	rehabilitation of old plant						
		2003	construc construction of new plant						
Intake Facilities		Tonle Sap		HWL = 10.78 m, LWL = 1.46m					
	Type	Raw Water Pumping							
	Intake Pump	(existing) :	36.7	m^3/min x	21	m x	3	units	
		(new) :	36.7	m^3/min x	21	m x	2	units	
Receiving Well									
	Type	Recutangular							
	Retention Time	4.1	min						
	Size & Q'ty	5.3	mW x	15	mL x	5.3 mD x	1	unit	
Name of Water Treatment Plant :		Phum Prek - Old							
Capacity		100,000	m^3/d	(Old)					
Treatment Process									
1.	Rapid Mixing								
2.	Flocculation								
3.	Sedimentation								
4	Filtration								
5	Disinfection								
Flocculation									
	Type	Horizontal Flow							
	Retention Time	24.8	min.						
	Size	8.0	mW x	11.0	mL x	3.27 mD			
	Q'ty	6	units						
	Equipment	Vertical Flocculator				6 units			
Sedimentation Tank									
	Type	Horizontal Flow							
	Retention Time	126.8	min	2.1	hr				
	Size	11	mL x	53	mW x	2.52 mD			
	Q'ty	6	units						
	Flow Velocity	0.52	m/min						
	Surface Load	119.2	mm/min						
	Trough/Pipe	Orifice Trough							
	Sludge Removal	Sludge Extraction Valve (Manual)							
	Equipment	Sludge Extraction Valve							
	Operation	Sludge Removal - Manual							
Filter									
	Type	Gravity, Single Media, Constant Flow, Level Control							
	Filtration rate	156	m/d (	6.50	m/hr)	170 m/hr at washing			
	Filter Bed Area	53.6	m^2						
	Size & Q'ty	4.5	mW x	11.9	mL x	12 filters			
	Filter Media	Sand : 0.8-1.0 mm x 1000 mm							
	Washing Rate	Air Scour :	0.934 m/min	Wash :	0.342 m/min	Rincing :		0.342 m/min	
	Washing System	Air Scouring (4 - 5 min), Air Scouring + Backwashing (4 - 7 min), Rincing (15 - 20 min)							
	Wash Trough	None							
	Equipment	Inlet Gate, Outlet Valve, Level Control Siphon, Siphon Regulation System							
		Washwater Inlet Valve,Washwater Discharge Gate, Washwater Pump							
		Scour Air Inlet Valve, Air Blower							
	Operation	Manual(Original-Automatic & Step-by-step)							
Sludge Disposal									
		Direct Discharge to the river							

Capacity		100,000 m^3/d (Old) 50,000 m^3/d (New)
Water Source		158,400 m^3/d Tonle Sap HWL = 10.9 m, LWL = 1.5m
Construction		1965 costruction of old plant
		1988, 1995 rehabilitation of old plant
		2003 construc construction of new plant
Intake Facilities		Tonle Sap HWL = 10.78 m, LWL = 1.46m
	Type	Raw Water Pumping
	Intake Pump	(existing) : 36.7 m^3/min x 21 m x 3 units
		(new) : 36.7 m^3/min x 21 m x 2 units
Receiving Well		
	Type	Recutangular
	Retention Time	4.1 min
	Size & Q'ty	5.3 mW x 15 mL x 5.3 mD x 1 unit
Name of Water Treatment Plant :		Phum Prek - Old
Capacity		100,000 m^3/d (Old)
Treatment Process		
1.	Rapid Mixing	
2.	Flocculation	
3.	Sedimentation	
4	Filtration	
5	Disinfection	
Flocculation		
	Type	Horizontal Flow
	Retention Time	24.8 min.
	Size	8.0 mW x 11.0 mL x 3.27 mD
	Q'ty	6 units
	Equipment	Vertical Flocculator 6 units
Sedimentation Tank		
	Type	Horizontal Flow
	Retention Time	126.8 min 2.1 hr
	Size	11 mL x 53 mW x 2.52 mD
	Q'ty	6 units
	Flow Velocity	0.52 m/min
	Surface Load	119.2 mm/min
	Trough/Pipe	Orifice Trough
	Sludge Removal	Sludge Extraction Valve (Manual)
	Equipment	Sludge Extraction Valve
	Operation	Sludge Removal - Manual
Filter		
	Type	Gravity, Single Media, Constant Flow, Level Control
	Filtration rate	156 m/d (6.50 m/hr) 170 m/hr at washing
	Filter Bed Area	53.6 m^2
	Size & Q'ty	4.5 mW x 11.9 mL x 12 filters
	Filter Media	Sand : 0.8-1.0 mm x 1000 mm
	Washing Rate	Air Scour : 0.934 m/min Wash : 0.342 m/min Rincing : 0.342 m/min
	Washing System	Air Scouring (4 - 5 min), Air Scouring + Backwashing (4 - 7 min), Rincing (15 - 20 min)
	Wash Trough	None
	Equipment	Inlet Gate, Outlet Valve, Level Control Siphon, Siphon Regulation System
		Washwater Inlet Valve,Washwater Discharge Gate, Washwater Pump
		Scour Air Inlet Valve, Air Blower
	Operation	Manual(Original-Automatic & Step-by-step)
Sludge Disposal		
		Direct Discharge to the river

Source: JICA Data Collection Survey Team

b. Operating Conditions

Although the WTP is operating properly, the city of Phnom Penh has high water demand and insufficient supply, so it is constantly operating under overload conditions. On the other hand, the original WTP was constructed in 1965. The first phase plant was renovated in 1988 and 1995, and the second phase facility was constructed in 2003. Deterioration and water leakage were observed in the concrete structure of the first stage, and some mechanical and electrical equipment has reached the end of its life and need to be renewed.

PPWSA considers the following to be the main problems of the Phum Prek WTP:

Raw Water Intake

- After the wet season, sand/silt accumulates around the intake tower and affects the quantity and quality of raw water.
- Due to land development, the buried electric cables are disturbed during construction, causing power outages and affecting facility operation.
- The piping (diameter 900 mm) connected to the intake air bell cell is old and may corrode and leak water.
- Since the flow meter has failed or is not installed in the raw water pipe, the amount of water intake cannot be measured.
-

Water Treatment Plan]

- The piping from the backwash blower and pump of the filtration pond is old, and there are air leaks and water leaks.
- The rapid/slow sand filter installed in the cohesive pond of the 1st stage 12 ponds is old and prone to failure.
- The rapid / slow sand filter installed in the cohesive pond of the 1st stage 12 ponds is old and prone to failure.
- The PAC injection equipment is old, the valve breaks down, and the injection amount cannot be controlled properly.
- In addition, there is only one injection facility, and it is difficult to repair in the event of a failure.
- Chlorine injection equipment is old, and it is difficult to procure spare liquid chlorine.

The problems at the intake station are expected to be resolved by the relocation of the intake station, which is scheduled to be implemented in parallel with the Phum Prek WTP renovation project that JICA is currently planning to implement. On the other hand, the problems that are occurring at the WTP are due to the aging that occurs on a daily basis for the time being, and it is important to prepare a budget every year and systematically upgrade the facilities. In particular, the 100,000 $m^{3/}$day old facility has already reached the end of its useful life in terms of mechanical and electrical equipment. Phase I facility is expecting to be completely re-construction.

c. Drainage Discharge Pipes

Settling basin sludge and backwash drainage from the filtration basin are discharged to the Sap River through drainage pipes.

A complete renovation of the old facility of 100,000 m^3/day is planned in this study, which includes the proposed construction of backwash wastewater and sludge treatment facilities for all facilities.

(3) Chroy Changvar WTP

1) Raw Water Transmission Mains

The general overview of the raw water intake, raw water transmission mains, and location of WTP is shown in ***Figure 6.1.21*** and ***Figure 6.1.22***.

Figure 6.1.21 Chroy Changvar - General Overview of the Raw Water Transmission Mains
Source: PPWSA

Raw water transmission main (800 mm diameter ductile cast iron pipe) for the 1st stage WTP was installed in 2002. The new raw water transmission main for the 2nd stage WTP was installed in 2009 using the same diameter ductile cast iron pipe. These two water transmission mains were installed in parallel and inter connection pipe was also installed.

The general profile from the raw water intake to the WTP is shown in ***Table 6.1.16***.

Table 6.1.16 Chroy Changvar - General Profile of the Raw Water Transmission Mains

LOCATION	DISTANCE (m)	GROUND LEVEL (m AMSL)	PIPE CROWN LEVEL (m AMSL)	EARTH COVERING (m)
Near Intake Station	0	+10.040	+9.280	0.760
Inside WTP	72.5	+7.528	+6.011	1.517

Source: JICA Data Collection Survey Team based on data provided by PPWSA

Figure 6.1.22 Chroy Changvar - General Overview of the Raw Water Transmission Mains
Source: PPWSA

2) Water Treatment Plant

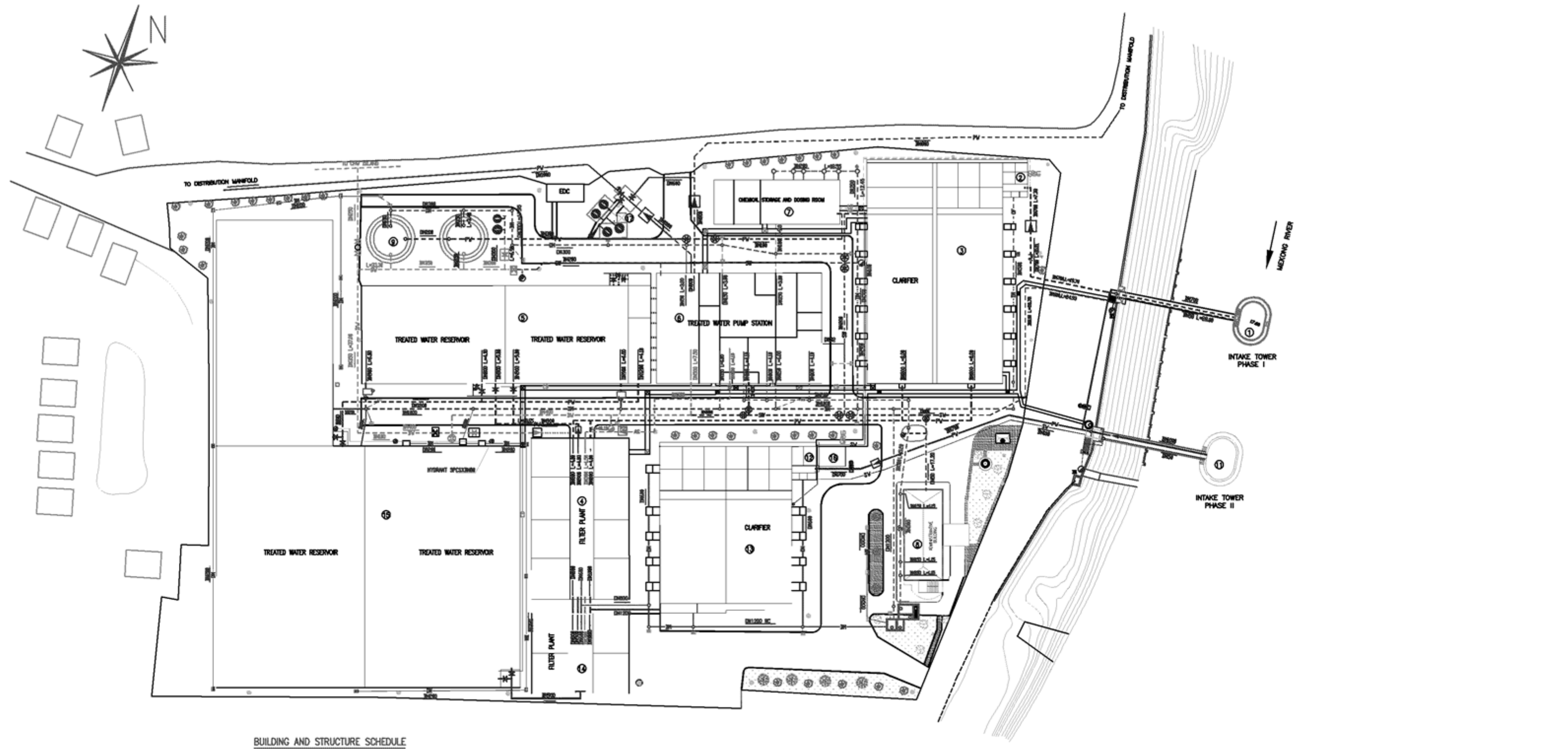
a. General

The general plan of the water treatment site and layout of the facilities is shown in ***Figure 6.1.23***.

Chroy Changvar WTP was constructed in two stages. The 1st stage plant with a production capacity of 65,000 m^3/day was constructed in 2002. The 2nd stage of the plant was constructed in 2009 and the total capacity was doubled to 130,000 m^3/day.

The process diagram and hydraulic profile of the water treatment is shown in ***Figure 6.1.24***.

Major equipment of the plant is shown in ***Figure 6.1.25*** and summarized in ***Table 6.1.17***.



BUILDING AND STRUCTURE SCHEDULE

No.	ITEM	DESCRIPTION	REMARK
①	INTAKE TOWER		PHASE I, RETAINED & REHABILITATED
②	MIXING TANKS	2.50m X 2.50m X 5.10m X 2	PHASE I
③	CLARIFIERS	38.40m X 13.10m X 4.70m X 2	PHASE I
④	FILTER PLANT	8.60m X 7.90m X 3.85m X 8	PHASE I
⑤	TREATED WATER RESERVOIRS	32.30m X 21.50m X 4.15m X 5000m^3	PHASE I
⑥	TREATED WATER PUMP STATION	36.60m X 24.00m	PHASE I
⑦	CHEMICAL STORAGE AND DOSING BUILDING	28.50m X 10.00m	PHASE I
⑧	ADMINISTRATIVE BUILDING	20.00m X 8.00m, 320m^2	PHASE I
⑨	ELEVATED WATER TANK	625m^3 EACH	PHASE I, RETAINED & REHABILITATED
⑩	GUARDHOUSE	6.36m X 5.50m, 70m^2	PHASE I, RETAINED & REHABILITATED
⑪	INTAKE TOWER		PHASE II
⑫	MIXING TANKS	2.50m X 2.50m X 5.10m X 2	PHASE II
⑬	CLARIFIERS	23.825m X 14.30m X 4.50m X 2	PHASE II
⑭	FILTER PLANT	8.60m X 7.90m X 3.85m X 4	PHASE II
⑮	TREATED WATER RESERVOIRS	50.105m X 46.525m X 4.15m 105.358m X 25.75m X 4.15m	PHASE II
⑯	NEUTRALIZATION ROOM	4.45m X 5.80m, 25.81m^2	PHASE II
⑰	AIR COMPRESSOR	2.2m X 2.2m, 4.84m^2	PHASE II

LEGENDS:

NEW WORK
PRIVATE HOUSING
EXISTING – RETAINED & REHABILITATED
EXISTING – DEMOLISHED
FUTURE FACILITY
PV — PROCESS WATER MAIN
BW — BACKWASH MAIN
AS — AIR SCOUR PIPE
SW — SERVICE WATER PIPE
BD — BACKWASH DRAIN
OF — OVER FLOW PIPE
CD — CHLORINE DOSING PIPE
AD — ALUM DOSING PIPE
LD — LIME DOSING PIPE
MOTOR VALVE & CHAMBER
DM — DRAIN MAIN
SP — SEWER PIPE
FLOW METER & CHAMBER
VALVE & CHAMBER
PRESSURE REDUCE VALVE & CHAMBER
VALVE (UNDER GROUND)
HYDRANT
SURGE TANK
MANHOLE
SEPTIC CHAMBER/OUTLET PENSTOCK CHAMBER
STORM RUNOFF INLET
ELECTRIC CABLE, DOSING PIPE DUCT AND MANHOLE
EXISTING UNDERGROUND SYSTEM (PHASE I)

NOTES:

1. DIMENSIONS, COORDINATES AND ELEVATIONS SHOWN IN METER.

Figure 6.1.23 Chroy Changvar - General Plan of the Water Treatment Site and Layout of The Facilities

Source: PPWSA

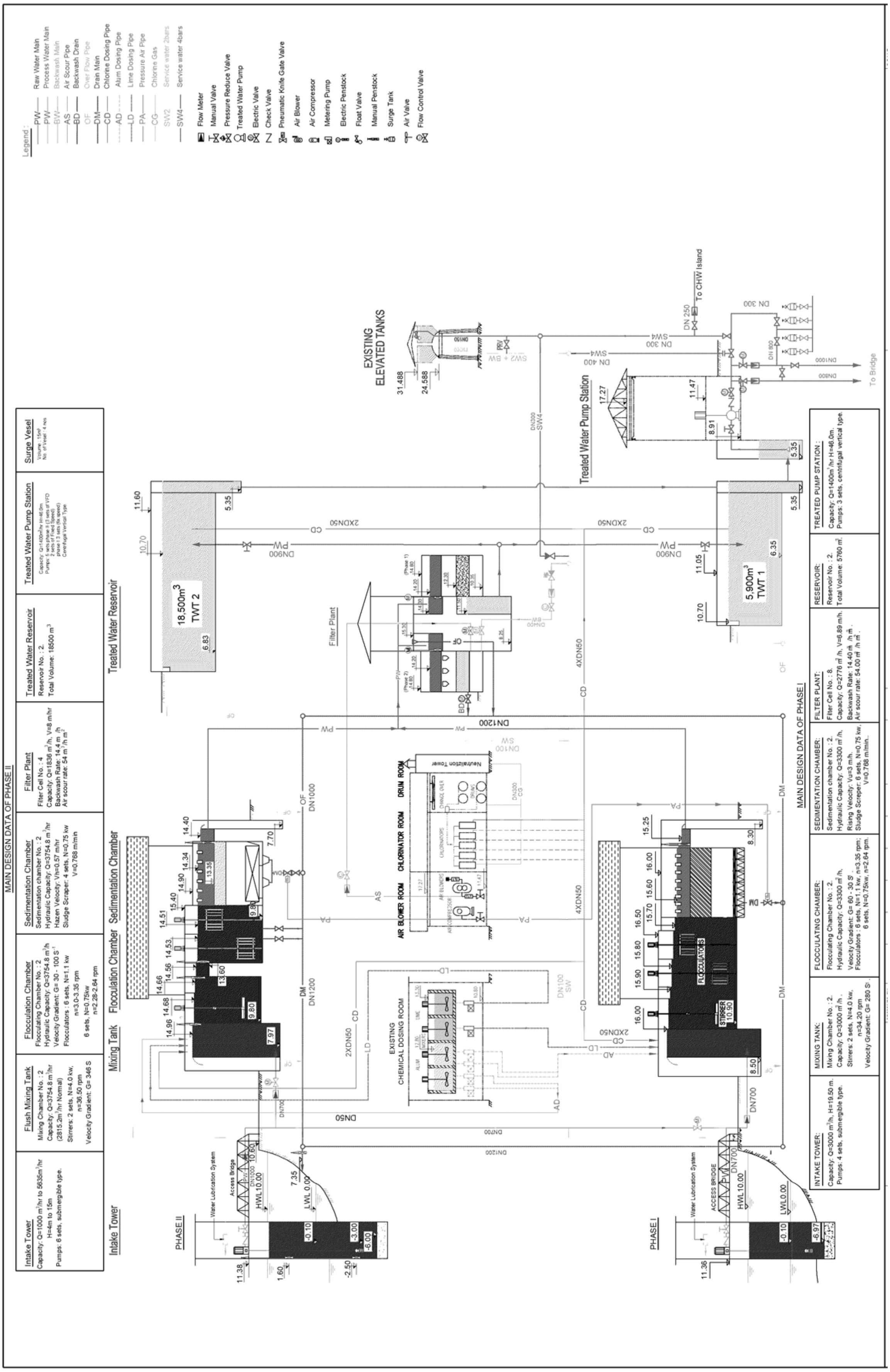


Figure 6.1.24 Chroy Changvar - Process Diagram and Hydraulic Profile of the Water Treatment

Source: PPWSA

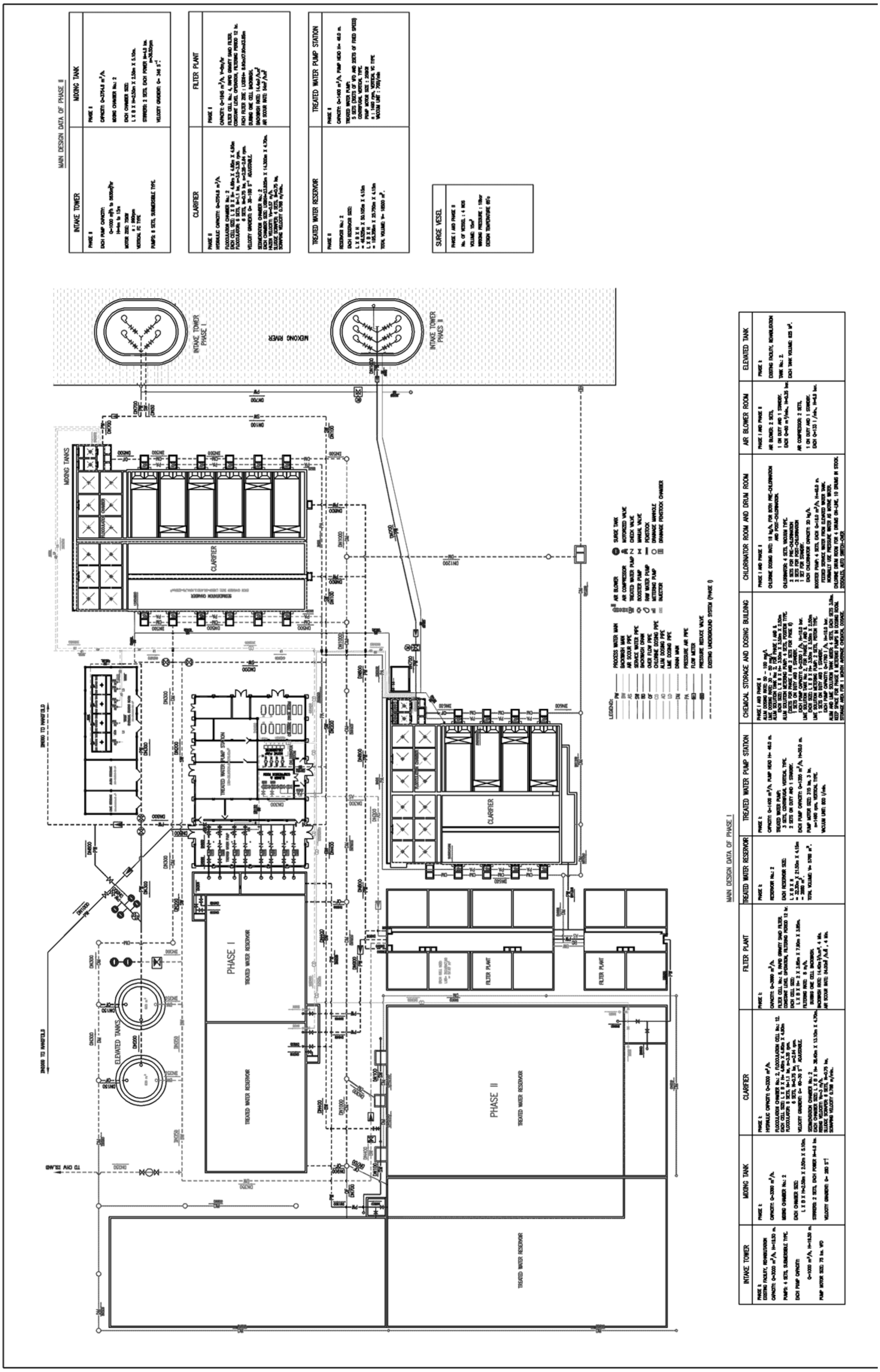


Figure 6.1.25 Chroy Changvar - Major Equipment of the Plant
Source: PPWSA

Table 6.1.17 Chroy Changvar - Major Facilities and Equipment of the Raw Water Intake Facilities

Capacity	65,000 m^3/d (1st Stage) 130,000 m^3/d (2nd Stage)
Water Source	136,500 m^3/d Mekong River HWL = 10.0 m, LWL = 0.0m
Construction	2002 costruction of 1st stage plant
	2009 costruction of intake and 2nd stage plant
Name of Water Treatment Plant :	Chroy Changvar (1st Stage)
Capacity	65,000 m^3/d
Treatment Process	
1. Rapid Mixing 2. Flocculation 3. Sedimentation 4 Filtration 5 Disinfection	
Intake Facilities	Pump Pit HWL = 10.0 m, LWL = -0.10m
Type	Raw Water Pumping
Intake Pump	23.7 m^3/min x 19.5 m x 5 units
Receiving Well	
Type	Recutangular
Retention Time	50.3 sec
Size & Q'ty	5.3 mW x 1.4 mL x 5.1 mD x 1 unit
Rapid Mixing	
Type	Mechnical Mixing
Retention Time	132 sec
Size & Q'ty	2.5 mW x 3.9 mL x 5.1 mD x 2 units
Equipment	Vertical Mixer 2 units
Flocculation	
Type	Horizontal Flow
Retention Time	25.9 min.
Size	4.6 mW x 4.6 mL x 4.6 mD
Q'ty	12 units
Equipment	Vertical Flocculator 12 units
Sedimentation Tank	
Type	Up Flow with Inclined Tube
Retention Time	114.3 min 1.9 hr
Size	38.4 mL x 14.3 mW x 4.7 mD
Q'ty	2 units
Surface Load	41.1 mm/min
Trough/Pipe	Orifice Trough
Sludge Removal	Sludge Scraper 12 units, Sludge Extraction Valve
Equipment	Inclined Tube, Sludge Scraper 12 units, Sludge Extraction Valve
Operation	Sludge Collection - Automatic, Sludge Removal - Automatic
Filter	
Type	Gravity, Single Media, Declining Flow
Filtration rate	1st Stage 141 m/d (5.87 m/hr) 188 m/d at washing
	2nd Stage 188 m/d (7.83 m/hr) 205 m/d at washing
Filter Bed Area	57.67 m^2 x 8 filters
Size & Q'ty	3.65 mW x 7.9 mL x 2 beds
Filter Media	Sand : 0.9 - 1.2 mm x 950 mm
Washing System	Air Scouring (54 m/hr) + Backwashing (14.4 m/hr)
Equipment	Inlet Gate, Outlet Valve, Washwater Valve, Air Scouring Valve, Washwater Drain Gate
	Washwater Pump, Air Scouring Valve, Air Blower
Operation	Manual
Chemicals	
Alum	Alum Tank + Mixer : 2 sets, Alum Dosing Pump : 2 (1)
Lime	Lime Tank + Mixer : 2 sets, Lime Dosing Pump : 2 (1)
Chlorine	Chlorinator -Pre : 2 (1) -Post : 2 (1), Pressure Pump : 4 (2)
Clear Water Reservoir	HWL = 6.35 m, LWL = 10.5 m
Elevated No. 1	625 m^3
Elevated No. 2	625 m^3
Reservoir No. 1	2,880 m^3
Reservoir No. 2	2,880 m^3
Clear Water Pump	
Distribution	22.58 m^3/min x 65 m x 315 kW x 3 units

Name of Water Treatment Plant :	Chroy Changvar (2nd Stage)
Capacity	65,000 m^3/d
Treatment Process	
1. Rapid Mixing 2. Flocculation 3. Sedimentation 4 Filtration 5 Disinfection	
Intake Facilities	Pump Pit HWL = 10.0 m, LWL = 0.00m
Type	Raw Water Pumping
Intake Pump	16.7 - 93.9 m^3/min x 4 - 15 m x 6 units
Receiving Well	
Type	Recutangular
Retention Time	61.3 sec
Size & Q'ty	5.3 mW x 1.4 mL x 6.2 mD x 1 unit
Rapid Mixing	
Type	Mechnical Mixing
Retention Time	153 sec
Size & Q'ty	2.5 mW x 4.6 mL x 5.0 mD x 2 units
Equipment	Vertical Mixer 2 units
Flocculation	
Type	Horizontal Flow
Retention Time	27.0 min.
Size	4.63 mW x 4.6 mL x 4.75 mD
Q'ty	12 units
Equipment	Vertical Flocculator 12 units
Sedimentation Tank	
Type	Up Flow with Inclined Tube
Retention Time	70.3 min 1.2 hr
Size	23.8 mL x 14.3 mW x 4.65 mD
Q'ty	2 units
Surface Load	66.1 mm/min
Trough/Pipe	Orifice Trough
Sludge Removal	Sludge Scraper 8 units, Sludge Extraction Valve
Equipment	Inclined Tube, Sludge Scraper 8 units, Sludge Extraction Valve
Operation	Sludge Collection - Automatic, Sludge Removal - Automatic
Filter	
Type	Gravity, Single Media, Declining Flow
Filtration rate	188 m/d (7.83 m/hr) 205 m/d at washing
Filter Bed Area	57.67 m^2 x 4 filters
Size & Q'ty	3.65 mW x 7.9 mL x 2 beds
Filter Media	Sand : 0.9 - 1.2 mm x 950 mm
Washing System	Air Scouring (54 m/hr) + Backwashing (14.4 m/hr)
Equipment	Inlet Gate, Outlet Valve, Washwater Valve, Air Scouring Valve, Washwater Drain Gate
	Washwater Pump, Air Scouring Valve, Air Blower
Operation	Manual
Clear Water Reservoir	HWL = 6.83 m, LWL = 10.7 m
Reservoir No. 1/2	18,500 m^3
Clear Water Pump	
Distribution-1	VFD 23.3 m^3/min x 46 m x 3 units
Distribution-2	Fixed 23.3 m^3/min x 46 m x 2 units

Source: JICA Data Collection Survey Team

b. Operating Conditions

Although the WTP is operating properly, the city of Phnom Penh has high water demand and insufficient supply, so it is constantly operating under overload conditions. On the other hand, as for the facility, the 1st phase facility was constructed in 2002 with a water production capacity of 65,000 m^3/day, and the 2nd phase construction was carried out in 2009 and it doubled to 130,000 m^3/day. About 20 years have passed since the mechanical and electrical equipment were installed in the 1st phase and malfunctions have begun to appear.

According to the PPWSA, there are currently no problems with operation. However, judging from the current condition of the facilities, it is necessary to upgrade the aging Phase I and Phase II mechanical and electrical equipment. It is hoped that a major upgrade of the facilities will be implemented in 2026 and 2027 to sustain the primary water purification capacity.

c. Drainage Discharge Pipes

Settling basin sludge and backwash drainage from the filtration basin are discharged to the Mekong River through drainage pipes.

If regulations on drainage and sludge discharge from the existing WTPs are tightened in the future and direct discharge is no longer possible, the filter backwash wastewater will be treated by collecting the supernatant water and the sludge combined with the sedimentation basin sludge. For this sludge treatment, backwash wastewater storage tanks and sludge storage tanks are desirable to the extent that land is available on the existing site, as it is difficult to purchase land near the WTP. The supernatant water in the backwash drainage is collected, and the remaining sludge and sedimentation tank sludge are stored in the sludge storage tank. The sludge should be transported by tank truck to a relatively nearby WTP for dewatering.

(4) Nirodh WTP

1) Raw Water Transmission Mains

The general overview of the raw water intake, raw water transmission main, and location of WTP is shown in ***Figure 6.1.26*** and ***Figure 6.1.27*** below.

Figure 6.1.26 Nirodh - General Overview of the Raw Water Transmission Mains
Source: JICA Data Collection Survey Team

The general profile from the raw water intake to the WTP is shown in ***Table 6.1.18*** below.

Table 6.1.18 Nirodh - General Profile of the Raw Water Transmission Mains

LOCATION	DISTANCE (m)	GROUND LEVEL (AMSL)	PIPE CROWN LEVEL (AMSL)	EARTH COVERING (m)
Intake Station	0.000	+11.240	+9.330	1.910
WTP	1,521.460	+11.500	+10.850	0.650

Source: JICA Data Collection Survey Team based on data provided by PPWSA

Raw water transmission main was installed in the 1st stage of the project in 2013. The 1600 mm diameter ductile cast iron raw water transmission main is able to meet the transmission requirement up to the Phase II plant. The main was reduced to 1200 mm and connected to the Phase I Plant. In the Phase II plant, the main was branched with a 1000 mm diameter ductile cast iron pipe and connected to the Phase II Plant. Raw water transmission main was installed in the following conditions.

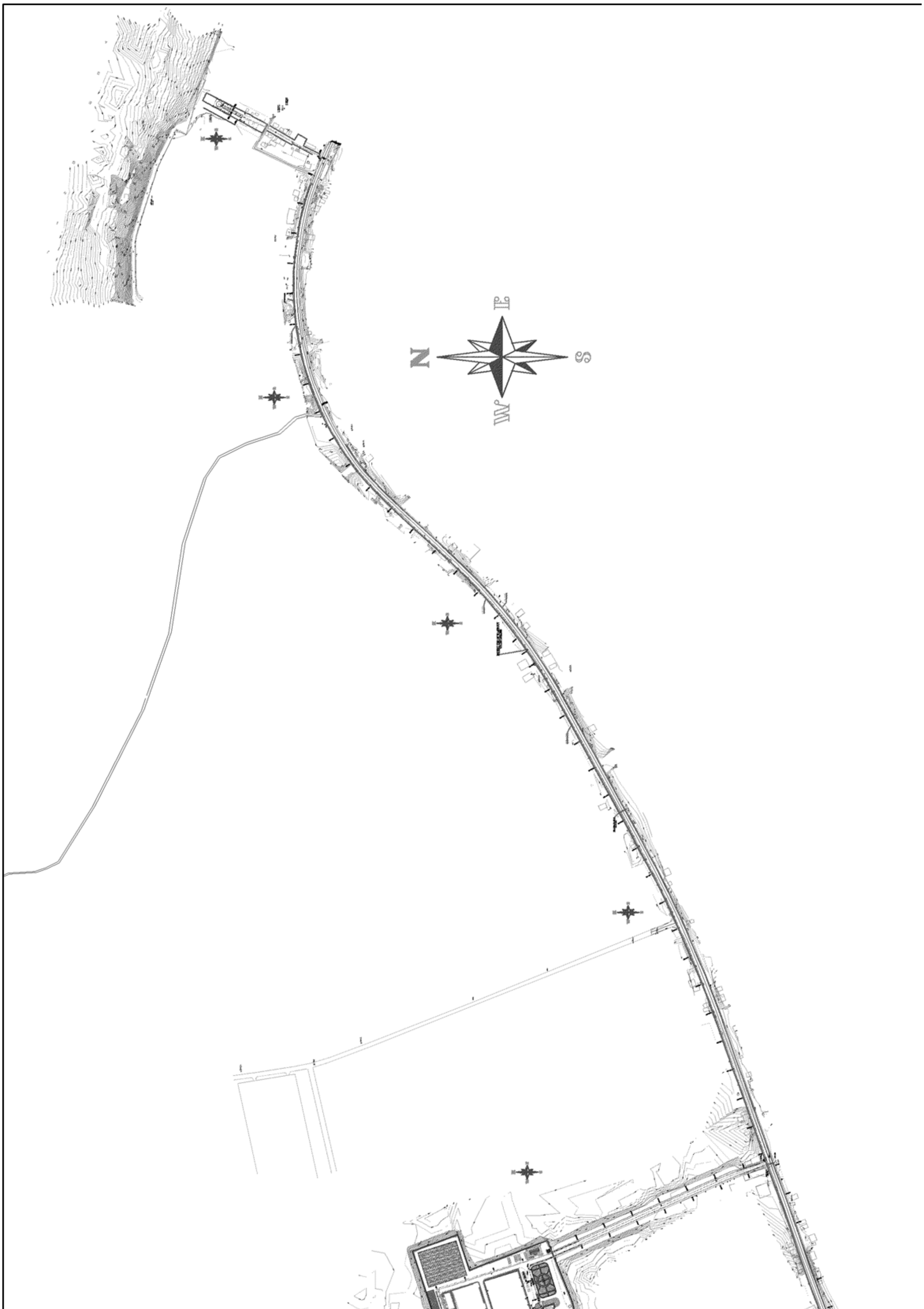


Figure 6.1.27 Nirodh - General Overview of the Raw Water Transmission Mains
Source: PPWSA

2) Water Treatment Plant

a. General

The general plan of the water treatment site and layout of the facilities is shown in ***Figure 6.1.28***.

Nirodh WTP was constructed in two stages. The Phase I plant with a production capacity of 65,000 m^3/day was constructed in 2002. Phase II of the plant was constructed in 2009 and the total capacity was doubled to 130,000 m^3/day.

The process diagram and hydraulic profile of the water treatment is shown in ***Figure 6.1.29*** below.

Major equipment of the plant is shown in ***Figure 6.1.30*** and summarized in ***Table 6.1.19***.

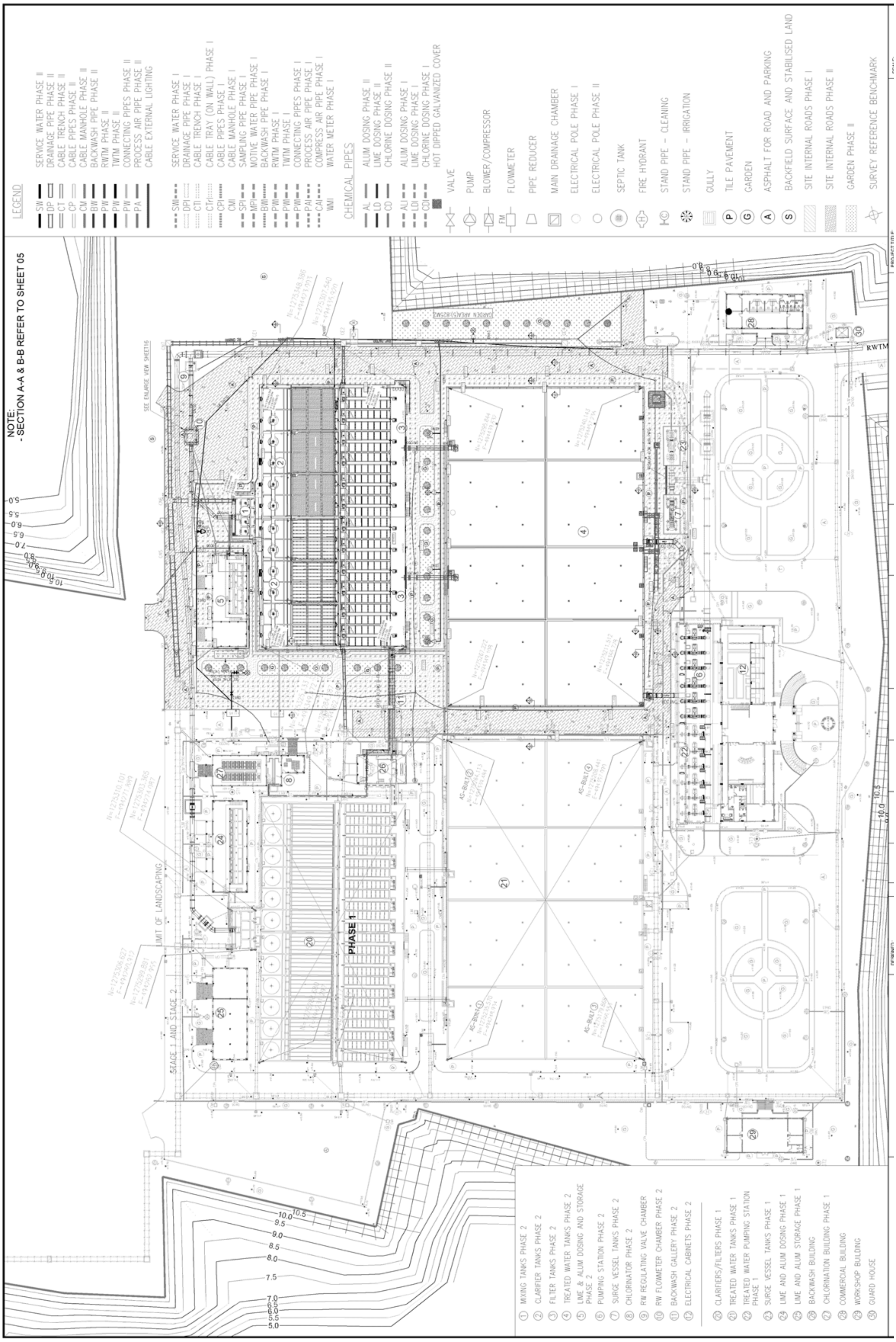


Figure 6.1.28 Nirodh - General Plan of the Water Treatment Site and Layout of The Facilities

Source: PPWSA

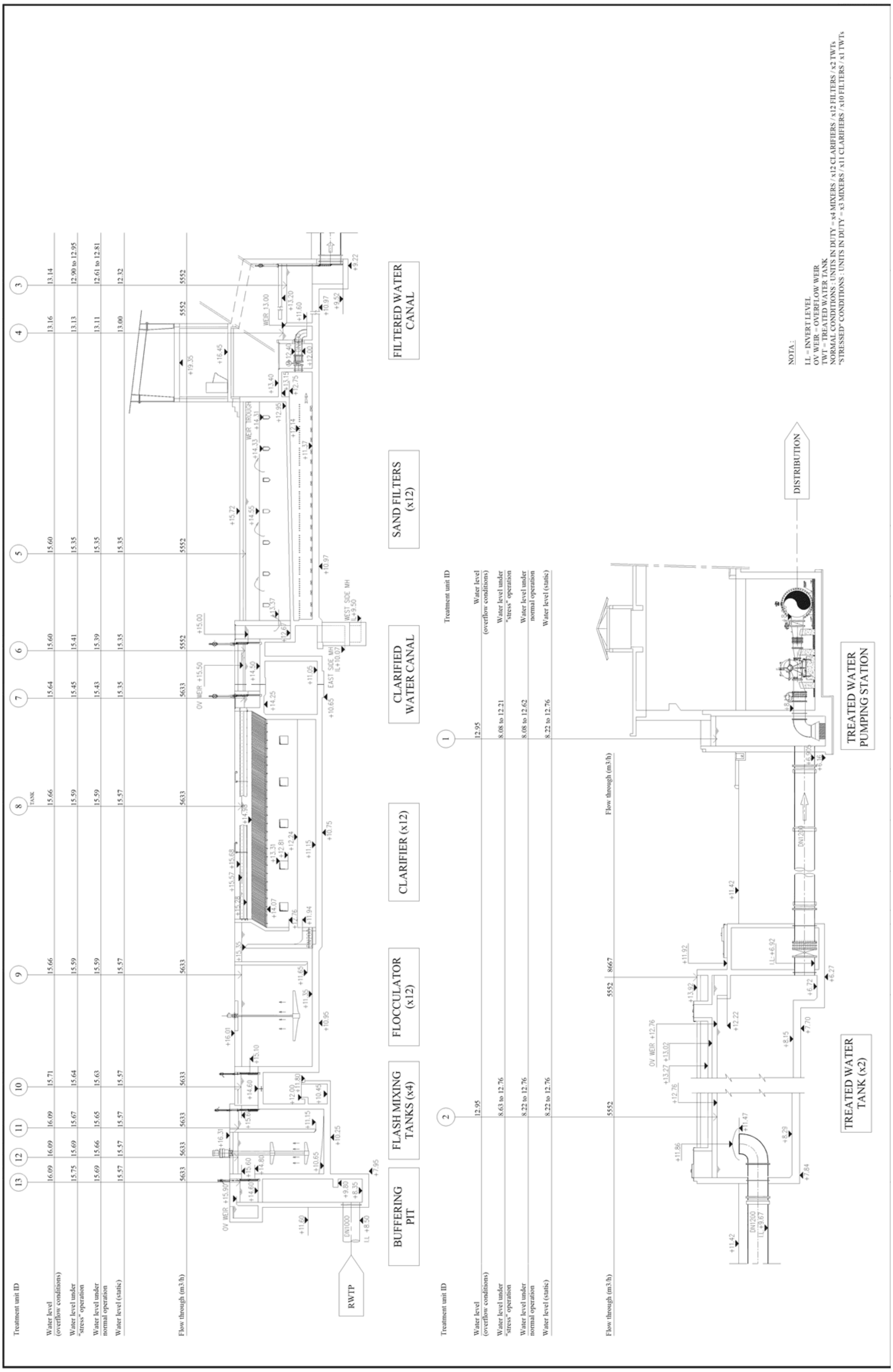


Figure 6.1.29 Nirodh - Process Diagram and Hydraulic Profile of the Water Treatment

Source: PPWSA

Table 6.1.19 Major Facilities and Equipment of the Raw Water Intake Facilities

Capacity	130,000 m^3/d	(1st Stage)	130,000 m^3/d	(2nd Stage)		
Water Source	270,000 m^3/d	Mekong River HHWL = 10.20 m, LLWL = 0.10 m				
Construction	2013	costruction of intake and 1st satage plant				
	2016	costruction of 2nd satage plant				
Name of Water Treatment Plant :	Nirouth - 1st Stage					
Capacity	130,000 m^3/d					
Intake Facilities	Mekong River	HWL = 9.20 m, LWL = 0.50 m				
Type	Raw Water Pumping					
Intake Pump	(1st Stage) 36.7	m^3/min x	17	m x	3	units (+1 standby)
Treatment Process						
1. Rapid Mixing						
2. Flocculation						
3. Sedimentation						
4 Filtration						
5 Disinfection						
Receiving Well						
Type	Recutangular					
Retention Time	9.0 sec					
Size & Q'ty	1.4 mW x	11.2 mL x	1.15 mD x	1 unit		
Rapid Mixing						
Type	Vertical Mixer					
Retention Time	1.4 min					
Size & Q'ty	2.5 mW x	2.5 mL x	5.04 mD x	4 units		
Equipment	None					
Flocculation						
Type	Vertical Mixer					
Retention Time	21 min					
Size & Q'ty	6.1 mW x	6.1 mW x	4.29 mD x	12 units		
Equipment	None					
Sedimentation Tank						
Type	Up-Flow with Lamella Plate (Tube Settler)					
Retention Time	58.2 min,	1.0 hr				
Size & Q'ty	16.5 mL x	6.1 mW x	4.34 mD x	12 units		
Surface Load	74.5 mm/min					
Trough/Pipe	Lamella Plate, Orifice Trough					
Sludge Removal	Sludge Extraction Valve (Pneumatic)					
Equipment	Sludge Extraction Valve					
Operation	Sludge Removal - Auto					
Filter						
Type	Gravity, Single Media, Constant Flow, Level Control					
Filtration rate	168 m/d (	7.00 m/hr)	183 m/hr at washing			
Filter Bed Area	64.4 m^2					
Size & Q'ty	2.45 mW x	2 beds x	13.14 mL x	12 filters		
Filter Media	Sand : 1.0 mm x 1000 mm					
Washing Rate	Air Scour : 0.116/0.88	m/min Wash :	0.168 m/min	Rincing :	0.334 m/min	
Washing System	Backwashing (1.0 min), Air Scouring + Backwashing (5 + 25 min), Rincing (8 min)					
Wash Trough	7 trough/bed x 2 beds/filter					
Equipment	Inlet Gate, Outlet Valve, Level Control Siphon, Siphon Regulation System					
	Washwater Inlet Valve,Washwater Discharge Gate, Washwater Pump					
	Scour Air Inlet Valve, Air Blower					
Operation	Automatic & Step-by-step					
Filter Backwash Recovery						
Recovery Tank	5.0 mW x	20.0 mL x	2 tanks			
Sludge Disposal						
Sludge Lagoon	40.0 mW x	100.0 mL x	4 tanks			
Chemicals						
Alum	Tank + Mixer : 3 , Dosing Pump : 3					
Lime	Tank + Mixer : 3, Lime Pump : 3					
Chlorine	Chlorinator -Pre : 3(1), -Post : 3(1)					
Clear Water Reservoir		HWL = 12.8 m, LWL = 8.37 m				
Reservoir	11,600 m^3 x	2 reservoirs				
Clear Water Pump		HWL = 13.2 m, LWL = 8.5 m				
Distribution	(1 to 6) 30.0	m^3/min x	53	m x	6 units	

Name of Water Treatment Plant :	Nirouth - 2nd Stage
Capacity	130,000 m^3/d
Intake Facilities	Mekong River HHWL = 10.20 m, LLWL = 0.10 m
Type	Raw Water Pumping
Intake Pump	(2nd Stage) 36.7 m^3/min x 17 m x 3 units (+1 standby)
Treatment Process	
1. Rapid Mixing 2. Flocculation 3. Sedimentation 4 Filtration 5 Disinfection	
Receiving Well	
Type	Recutangular
Retention Time	11.8 sec
Size & Q'ty	1.4 mW x 11 mL x 1.15 mD x 1 unit
Rapid Mixing	
Type	Vertical Mixer
Retention Time	1.4 min
Size & Q'ty	2.5 mW x 2.5 mL x 5.04 mD x 4 units
Equipment	None
Flocculation	
Type	Vertical Mixer
Retention Time	21 min
Size & Q'ty	6.1 mW x 6.1 mW x 4.29 mD x 12 units
Equipment	None
Sedimentation Tank	
Type	Up-Flow with Lamella Plate (Tube Settler)
Retention Time	45.0 min, 0.8 hr
Size & Q'ty	12.5 mL x 6.1 mW x 4.44 mD x 12 units
Surface Load	98.7 mm/min
Trough/Pipe	Lamella Plate, Orifice Trough
Sludge Removal	Sludge Extraction Valve (Pneumatic)
Equipment	Sludge Extraction Valve
Operation	Sludge Removal - Auto
Filter	
Type	Gravity, Single Media, Constant Flow, Level Control
Filtration rate	168 m/d (7.00 m/hr) 183 m/hr at washing
Filter Bed Area	64.4 m^2
Size & Q'ty	2.45 mW x 2 beds x 13.14 mL x 12 filters
Filter Media	Sand : 1.0 mm x 1000 mm
Washing Rate	Air Scour : 0.116/0.88 m/min Wash : 0.168 m/min Rincing : 0.334 m/min
Washing System	Backwashing (1.0 min), Air Scouring + Backwashing (5 + 25 min), Rincing (8 min)
Wash Trough	7 trough/bed x 2 beds/filter
Equipment	Inlet Gate, Outlet Valve, Level Control Siphon, Siphon Regulation System
	Washwater Inlet Valve,Washwater Discharge Gate, Washwater Pump
	Scour Air Inlet Valve, Air Blower
Operation	Automatic & Step-by-step
Filter Backwash Recovery	
Recovery Tank	5.0 mW x 20.0 mL x 2 tanks
Sludge Disposal	
Sludge Lagoon	40.0 mW x 100.0 mL x 4 tanks
Chemicals	
PAC	Tank + Mixer : 2 , Dosing Pump : 2
Lime	Tank + Mixer : 2, Lime Pump : 2
Chlorine	Chlorinator -Pre : 3(1), -Post : 3(1)
Clear Water Reservoir	HWL = 12.76 m, LWL = 8.22 m
Reservoir	12,260 m^3 x 2 reservoirs
Clear Water Pump	HWL = 13.2 m, LWL = 8.5 m
Distribution	(7 to 12) 30.0 m^3/min x 53 m x 6 units

Source: JICA Data Collection Survey Team

b. Operating Conditions

The 1st phase of the WTP was constructed in 2013 with a production capacity of 130,000 m^3/day, and the second phase of construction was carried out in 2016, doubling the total water treatment capacity to 260,000 m^3/day. Now this plant is the largest WTP in PPWSA. This WTP is operating properly, but water demand in Phnom Penh is high, and the plant operation is often adjusted to cope with the fluctuation.

PPWSA points out the following problems that hinder proper and stable operation:

- The quality of raw water fluctuates due to earth and sand filling for the construction on Norea Island. It makes difficult to operate the plant and to determine chemical usage.
- In the dry season, the water level of rivers is low, the amount of water taken by pumps is insufficient, and the water production is insufficient.
- Seashells are growing abnormally in the intake pump wells and raw water transmission pipes. It occurs at other WTPs, but it is less than at Nirodh WTP.

The above problem is related to the water intake station. With the current construction of Norea Island, the existing intake station will be discontinued, and a new intake station will be constructed on Norea Island. When constructing the new intake station, it is desirable to design the facility with measures to solve the above problems.

c. Drainage Discharge Pipes

Settling basin sludge and backwash drainage from the filtration basin are discharged to the Bassac River through drainage pipes.

As regulations will be tightened in the future, it is necessary to construct wastewater treatment and sludge treatment facilities for sedimentation basin sludge and filter basin backwash wastewater from the facilities constructed in Phase I and Phase II during the construction of Phase III.

(5) Chamcar Mon WTP

1) Raw Water Transmission Mains

The general overview of the raw water intake, raw water transmission mains, and location of WTP is shown in ***Figure 6.1.30*** and ***Figure 6.1.31***.

Figure 6.1.30 General Overview of the Raw Water Transmission Mains

Source: PPWSA

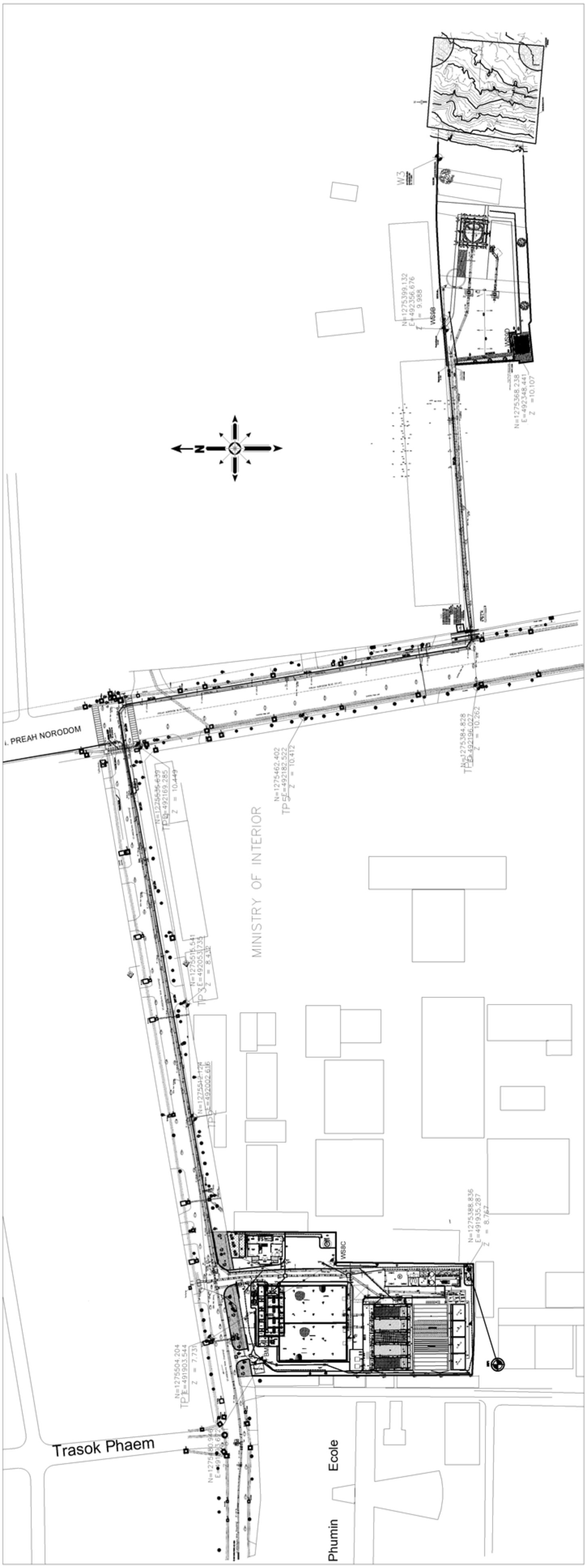


Figure 6.1.31 Chamcar Mon - General Overview of the Raw Water Transmission Mains
Source: PPWSA

2) Water Treatment Plant

a. General

The general plan of the water treatment site and layout of the facilities is shown in ***Figure 6.1.32***.

Chamcar Mon WTP was constructed in 2019 with a production capacity of average 52,000 $m^{3/}$day, and maximum 55,000 m^3/day.

The process diagram and hydraulic profile of the water treatment is shown in ***Figure 6.1.33*** below.

Major equipment in the raw water intake facilities is summarized in ***Table 6.1.20*** below.

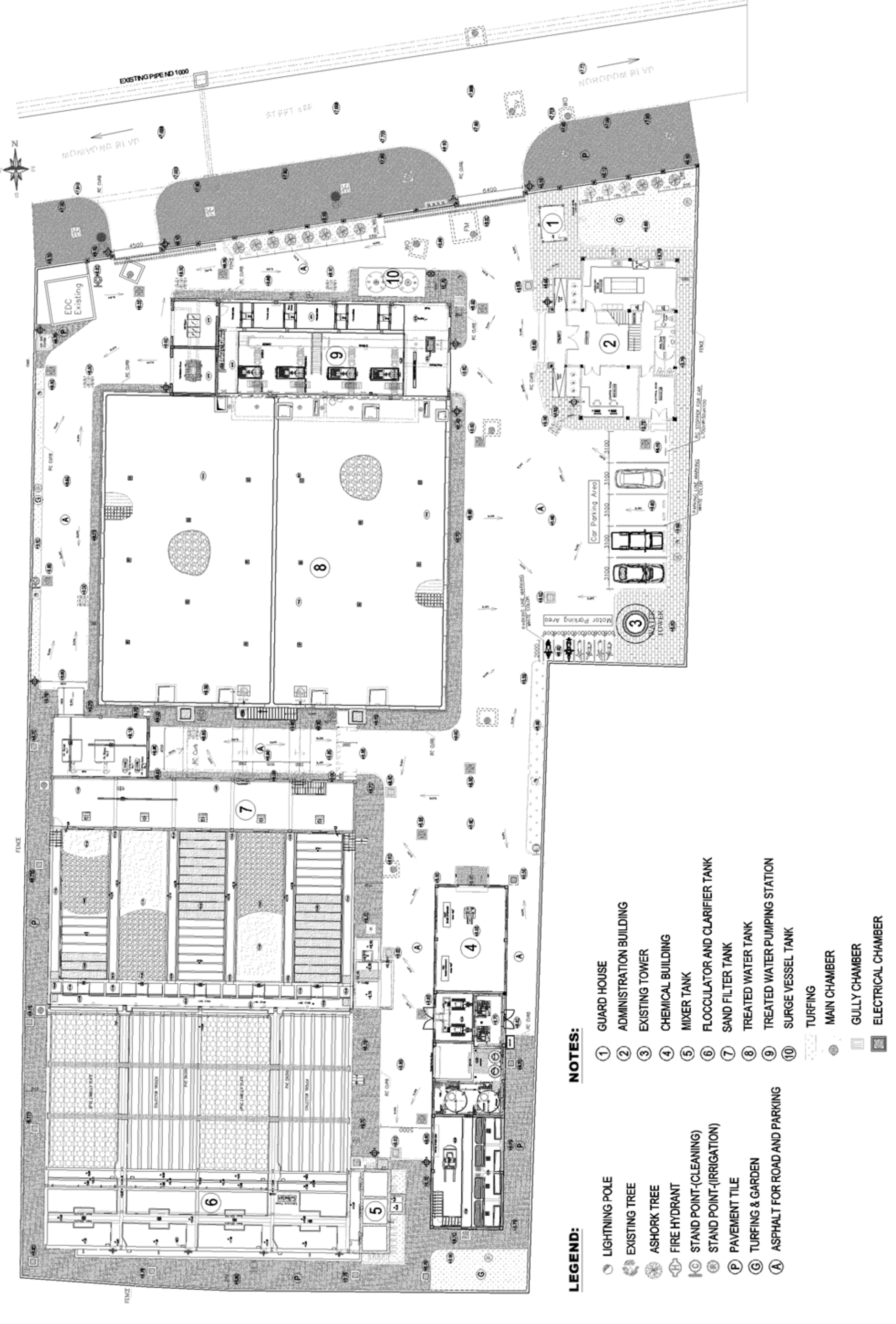


Figure 6.1.32 Chamcar Mon - General Plan of the Water Treatment Site and Layout of the Facilities
Source: PPWSA

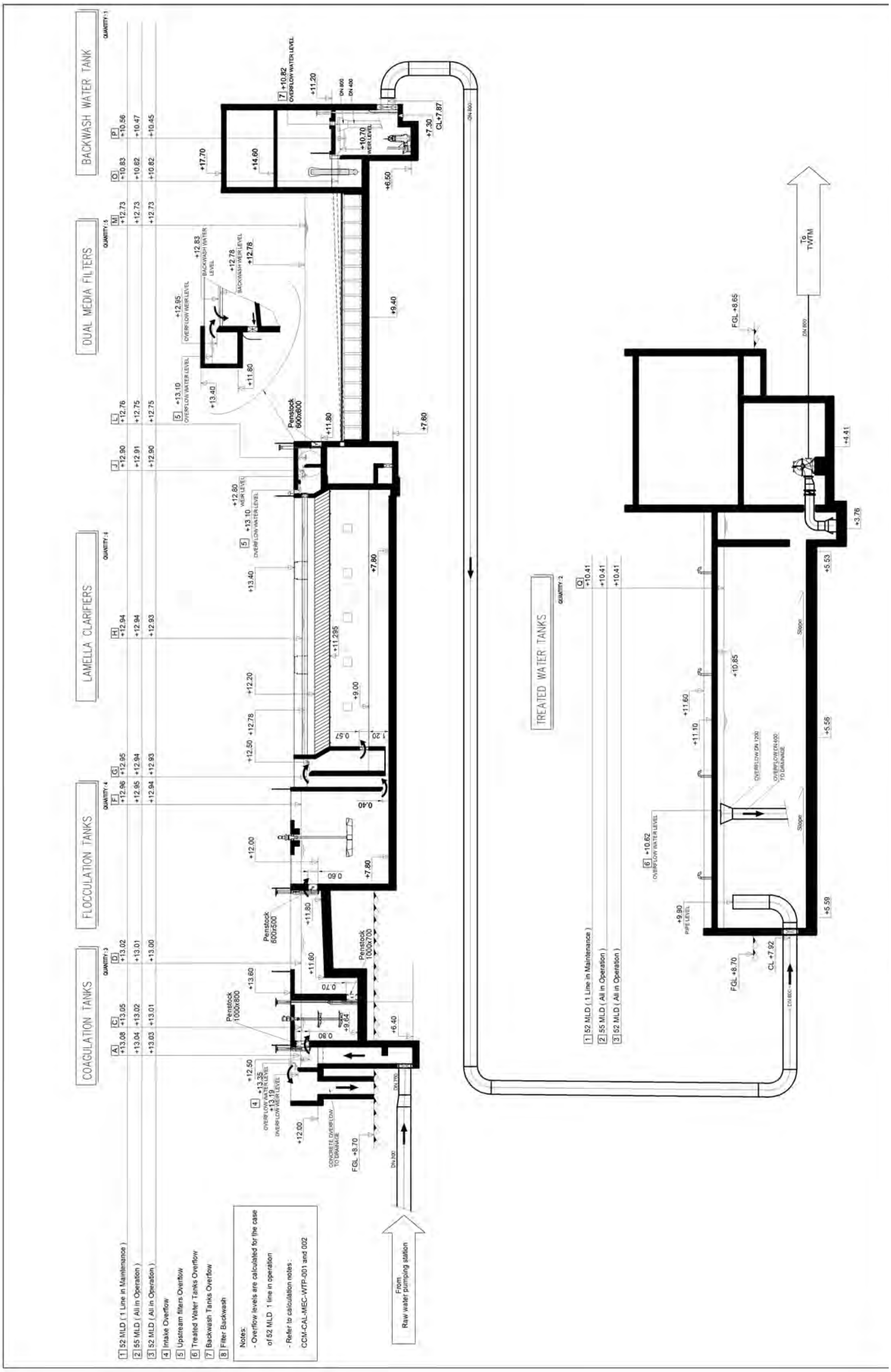


Figure 6.1.33 Chamcar Mon - Process Diagram and Hydraulic Profile of the Water Treatment
Source: PPWSA

Table 6.1.20 Chamcar Mon - Major Facilities and Equipment of the Raw Water Intake Facilities

Capacity	Nominal 52,000 m^3/d Maximum 55,000 m^3/d
Water Source	Tonle Basak HWL = 10.20 m, LWL = - 0.07 m
Construction	1957 costruction of old plant
	1988 rehabilitation of old plant
	1995 construction of new plant
	2019 construction of new plant
Treatment Process	
1. Rapid Mixing 2. Flocculation 3. Sedimentation 4 Filtration 5 Disinfection	
Intake Facilities	Tonle Bassac
Type	Raw Water Pumping
Equipment	Intake Pump : 13.2 m^3/min x 18.5 m x 75 kW x 4
Receiving Well	
Type	Recutangular
Retention Time	29.4 sec
Size & Q'ty	1.4 mW x 11 mL x 1.15 mD x 1 unit
Rapid Mixing	
Type	Vertical Mixer
Retention Time	1.7 min
Size & Q'ty	2.4 mW x 2.4 mL x 3.46 mD x 3 unit
Equipment	None
Flocculation	
Type	Vertical Mixer
Retention Time	22.3 min
Size & Q'ty	7.09 mW x 5.5 mL x 5.17 mD x 4 unit
Equipment	None
Sedimentation Tank	
Type	Inclined Plate + Up-Flow
Retention Time	1.0 hr
Size & Q'ty	7.09 mW x 15.2 mL x 5.16 mD x 4 unit
Surface Load	83.8 mm/min
Trough/Pipe	Orifice Trough
Sludge Removal	Sludge Wihtdrawal Valve
Equipment	Inclined Plate, Orifice Trough, Sludge Wihtdrawal Valve
Operation	Sludge Removal-Mamual
Filter	Horizontal Cylindrical Pressured Filter
Type	Open, Dual Media, Costant Rate, Costant Level
Filtration rate	155 m/d (6.4592 m/hr) 194 m/hr at washing
Filter Bed Area	67.09 m^2 x 5 filters
Size & Q'ty	4.57 m Dia. x 14.7 mL x 5 filters
Filter Media	Sand : 1.0 mm x 1000 mm
Washing System	Air Scouring (5-8 min) + Backwashing (10-15 min)
Washing Rate	Air Scour : 0.205 m/min Backwash : 0.056 m/min
Trough	Both side of filter
Equipment	Inlet Gate, Outlet Valve, Outlet Level Control Syphon, Backwash Valve, Drain Valve
	Backwash Pump, Air Scouring Valve, Air Blower
Operation	Auto/Manual
Chemicals	
PAC	Tank + Mixer : 2 , Dosing Pump : 2 (1)
Lime	Tank + Mixer : 2, Dosing Pump : 2 (1)
Chlorine	Electrolyser - Pre : 1, - Post : 1, Dosing Pump - Pre : 2 (1), - Post : 2 (1)
Sludge Disposal	
	Direct Discharge to the river
Clear Water Reservoir	HWL = 10.41 m, LWL = 5.53 m
	2,400 m^3 x 2 Reservoirs
Clear Water Pump	
Distribution	18.3 m^3/min x 45 m x 315 kW x 4 units

Source: PPWSA

b. Operating Conditions

This WTP was constructed in 2019 and is in good operation.

c. Drainage Discharge Pipes

Settling basin sludge and backwash drainage from the filtration basin are discharged to the Bassac River through drainage pipes.

If regulations on drainage and sludge discharge to existing WTPs are tightened in the future and direct discharge is no longer possible, the filtration basin backwash wastewater will be treated by collecting the supernatant water and combining it with the sedimentation basin sludge. For this sludge treatment, backwash wastewater storage tanks and sludge storage tanks are desirable to the extent that land is available on the existing site, as it is difficult to purchase land near the WTP. The supernatant water in the backwash drainage is collected, and the remaining sludge and sedimentation tank sludge are stored in the sludge storage tank. The sludge should be transported by tank truck to a relatively nearby WTP for dewatering.

6.2 PROPOSED FUTURE DEVELOPMENT

6.2.1 New Raw Water Intake Facilities

Based on the study about candidates of water sources shown in ***Chapter 5***, the location of existing water treatment facilities, and the candidate sites for new WTPs, the water intake facilities that are proposed to be newly constructed by 2030 are shown in ***Table 6.2.1***.

Table 6.2.1 Location Overview of New Raw Water Intake Facility

Name	Location	Target WTP	Projected Capacity (m^3/day)	Target Year of Construction	Status of Land Adquisition
Bakheng Phase III intake	Mekong River (Right bank), Bakheng	Bakheng WTP Phase III (Expansion)	195,000	2027	Land adquisition terminated
Nirodh intake	Mekong River (Right bank) Nirodh, Koh Norea	Nirodth WTP Phase III (Expansion)	130,000	2029	Allocation agreed in the new reclaimed area by the contractor
Koh Norea intake		Koh Norea WTP (New)	150,000	2029	
Ta Mouk intake	Sap River (Right bank) Preak Prov	Ta Mouk WTP Phase I (New)	200,000	2030	Land adquisition required
		Ta Mouk WTP Phase II (Expansion)	200,000	2031	
		Ta Mouk WTP Phase III* (Expansion)	200,000	After 2033	
Khsach Kandal intake	Mekong River (Left bank), Khsach	Khsash Kandal WTP (New)	100,000	2030	Land adquisition required
New Airport City intake	Bassac River (Right bank), Setbou	New Airport City WTP (New)	30,000	2030	Land adquisition required

*1: Regarding the water intake facility for Phase III, it is assumed that only the land and pump facility space will be secured.
Source: JICA Data Collection Survey Team

Since the location conditions of the new intake facility are similar to those of the following facilities, the concept of these designs will be followed.

- Bakheng intake facility and existing Nirodh intake facility on the Mekong River
- Phum Prek intake facility on the Sap River
- Chamcar Mon intake facility on the Bassac River

The items to be considered for the design of the intake facility are shown below.

- Geological and topographical conditions at the facility construction site
- Design water level of intake facilities based on river water level conditions (HWL, LWL etc.)
- Scale and specifications of raw water intake facilities based on the required amount of treated water
- Type of raw water intake structure
- Layout of raw water intake facilities
- Protection of riverbed and riverbank
- Construction cost
- Constraints on operation of raw water intake facilities
- Positional relation between raw water intake and WTP (distance, elevation etc.)
- Proactive response to anticipatory concerns

(1) Location of New Raw Water Intake Facilities

1) Raw Water Intake Facilities of Bakheng Phase III

The Bakheng Phase III raw water intake facility is planned to be located downstream of the Phase I and Phase II intake facilities that are currently under construction (as of 2021). PPWSA has already secured about 0.5 ha of land on the right bank of the Mekong River (See ***Table 6.2.1*****Location Overview of New Raw Water Intake Facility**).

The distance from this candidate site to the Bakheng WTP is about 2.1 km.

As a result of calculating the water level conditions at the location of the raw water intake facility based on the past actual water levels at the surrounding stations, it was estimated that the maximum water level at the candidate site was 10.81 m AMSL and the minimum water level was 0.33 m AMSL.

Figure 6.2.1 Positional relation between Raw Water Intake and WTP (Bakheng Phase III)
Source: JICA Data Collection Survey Team

Figure 6.2.2 Appearance of candidate site for Raw Water Intake Facility (Bakheng Phase III)
Source: Photo taken by PPWSA on Dec 27, 2020

2) Raw Water Intake Facilities of Nirodh and Koh Norea

Due to the ongoing reclamation of the Mekong River near the Nirodh area and the construction of the Koh Norea, it is necessary to relocate the existing raw water intake facility of the Nirodh WTP.

An agreement between PPWSA and the reclamation development company specifies that the existing intake facility will be relocated along the Mekong River in Koh Norea. (See ***Figure 6.2.3***)

It has been agreed that the cost of relocating the existing Nirodh intake facility will be borne by the developers of Koh Norea and that land will be provided for that purpose. However, the arrangement of cost burden when developing the water intake facility including the expansion remains as a future issue.

The details of the design of the water intake facility after the relocation (type of structure and method of water capture, etc.) are unknown, but the assumed relocation location is as shown in ***Figure 6.2.3***.

In addition to Nirodh, Koh Norea also needs a water treatment facility to prepare for future expansion of water demand, and the raw water intake facility and water treatment facility will be secured at the Koh Norea reclaimed site. According to the development plan, approximately 2 ha of land for PPWSA is expected to be secured, but the specific location of the facility site has not been decided.

Figure 6.2.3 Candidate Location of Intake Facilities for Nirodh and Koh Norea
Source: Prepared by JICA Data Collection Survey Team with information provided by PPWSA

As a result of calculating the water level conditions at the location of the intake facility based on the past actual water levels at the surrounding stations, it was estimated that the maximum water level at the candidate site was 9.83 m AMSL and the minimum water level was 0.21 m AMSL.

3) Raw Water Intake Facilities of Ta Mouk

Approximately 25 ha of PPWSA-owned land in the reclaimed land of Lake Ta Mouk is expected to be secured as a WTP site, and it is desirable to construct a Ta Mouk raw water intake facility on the right bank of the Sap River, which is the closest water source candidate. ***Figure 6.2.4*** and ***Figure 6.2.5*** show candidate sites for the construction of the Ta Mouk raw water intake facility, taking into consideration the possibility of securing land and drainage inflow points. It is located about 20 km upstream from the confluence with the Mekong River, and the planned waterworks site is about 8.6 km.

As a result of calculating the water level conditions at the location of the raw water intake facility based on the past actual water levels at the surrounding stations, it was estimated that the maximum water level at the candidate site was 10.27 m AMSL and the minimum water level was 0.36 m AMSL.

Figure 6.2.4 Positional Relation Between Raw Water Intake and WTP (Ta Mouk)
Source: JICA Data Collection Survey Team

Figure 6.2.5 Appearance of Candidate Site for Intake Facility (Ta Mouk)
Source: Photo taken by JICA Data Collection Survey Team on Oct 01, 2021

4) Raw Water Intake Facilities of Khsach Kandal

The right bank of the Mekong River (on the opposite bank of central Phnom Penh) and some areas in Kandal Province will be incorporated into Phnom Penh in the future. In order to provide water supply to this area, it is desirable to install a raw water intake facility that uses the Mekong River as its water source. ***Figure 6.2.6*** and ***Figure 6.2.7*** show candidate raw water intake points in the Khsach Kandal area, considering the possibility of securing land and accessibility from the metropolitan area.

Figure 6.2.6 Positional Relation Between Raw Water Intake and WTP (Khsach Kandal)
Source: JICA Data Collection Survey Team

Figure 6.2.7 Appearance of Candidate Site for Raw Water Intake Facility (Khsach Kandal)
Source: Photo taken by JICA Data Collection Survey Team on Oct 01, 2021

5) Raw Water Intake Facilities of New Airport City

In order to supply water to the area around the new airport, which is expected to be developed along with the construction of the new airport, JICA Data Collection Survey Team proposes a raw water intake facility with the Bassac River as the water source and a nearby WTP. ***Figure 6.2.8*** and ***Figure 6.2.9*** show the area where the candidate sites for the construction of the New Airport City raw water intake facility and WTP should be located, considering the possibility of securing land and the water conveyance distance to the demand area.

The recommended conditions for the location of the raw water intake facility are as follows.

- A section on the left bank of the Bassac River where there is no extreme riverbank erosion or sediment accumulation for securing stable raw water intake.
- A section outside the bend of the river channel (a place where the slope of the riverbed in the crossing direction is relatively large with respect to the distance from the riverbank, that is, the water depth is large).

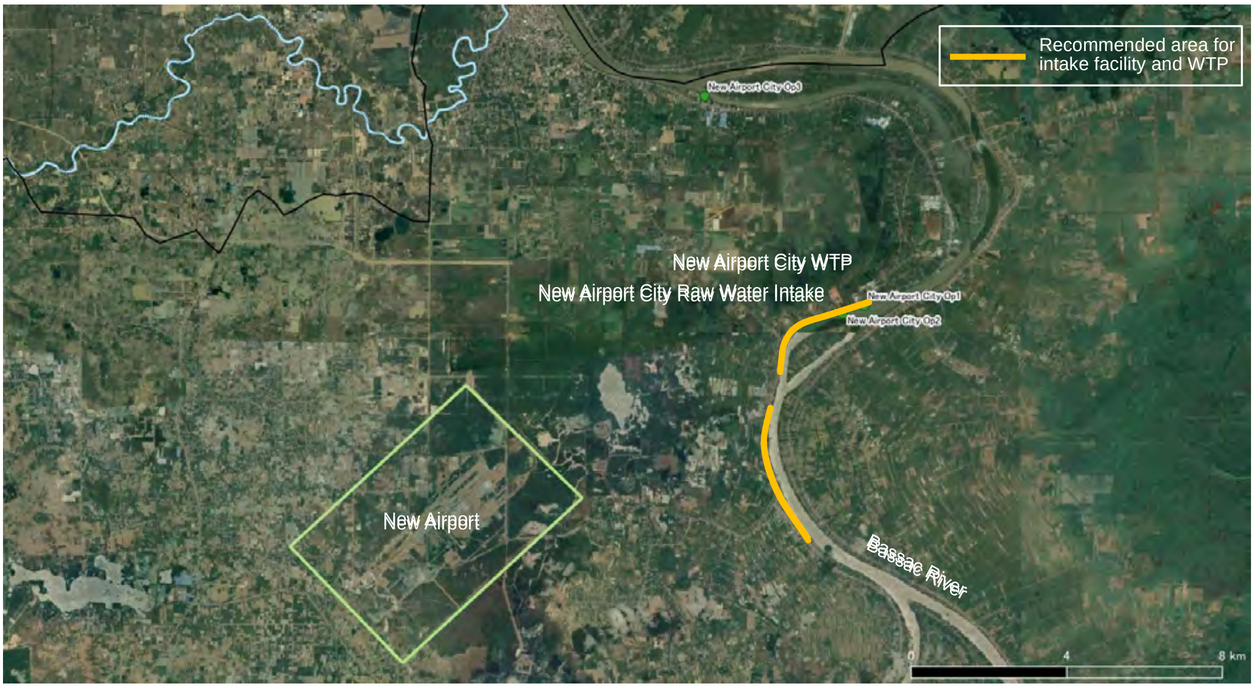


Figure 6.2.8 Positional relation Between Raw Water Intake and WTP (New Airport City)
Source: JICA Data Collection Survey Team

Figure 6.2.9 Appearance of Candidate Site for Raw Water Intake Facility of New Airport City (Option 1)
Source: JICA Data Collection Survey Team

(2) Comparison of Raw Water Intake Methods

The raw water intake method is selected by comprehensively judging the annual water level fluctuation, workability, impact on the surrounding area, etc. of each water source.

Focusing on the annual water level fluctuation, it extends to about 14 m in the Mekong River and about 8 m in the Sap River. In addition, considering the width of rivers and risks during floods, it is difficult to construct structures such as intake weirs and intake gates.

The raw water intake method for the new raw water intake facility will be proposed by comparing and examining the following four plans.

- Direct Intake Tower
  This is a method in which a reinforced concrete or steel intake tower is installed about 50 m offshore from the current embankment line in the direction of the river, and river water is taken in from the opening on the wall of the tower and pumped up.

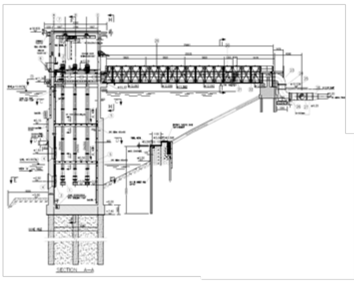
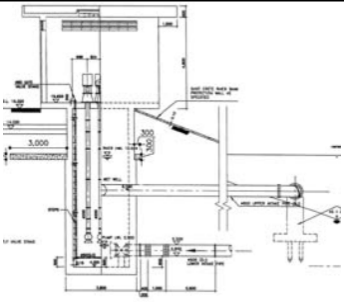
- Intake Tower with Extended Pipe
  This is a method in which a raw water intake pipe is extended from the inside of the bank to the river side, and the river water is conducted by gravity flow to a water chamber installed underground inside the bank and pumped up to WTP.

- Inclined Pipe
  This is a method in which a raw water intake pipe is extended in the direction of the river along the slope of the embankment and raw water is taken by a submersible pump installed at the end of the intake pipe.

- Vertical Wall Gate with Intake Channel
  This is a method in which a structure consisting of a vertical wall gate and a raw water intake channel is installed on the revetment, and river water can be directly taken in and pumped according to different water levels.

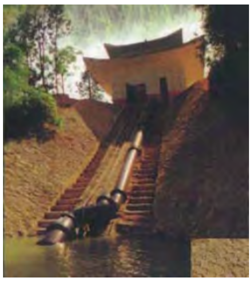
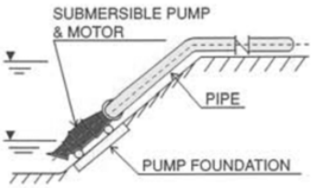
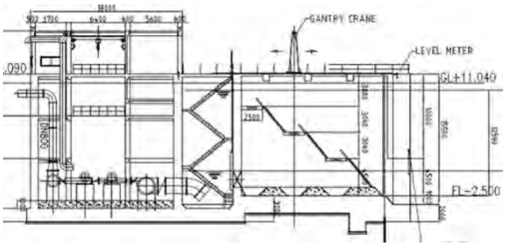
Table 6.2.2 shows the basic elements of each method in selecting the raw water intake method.

Table 6.2.2 Basic Elements of Different Raw Water Intake Method (1/2)

Item	Direct Intake Tower	Intake Tower with Extended Pipe
Example photo		
Example drawing		
Outline of facilities	➢ A reinforced concrete or steel intake tower is built near the riverbank, and water is taken from the opening set on the wall of the tower. ➢ The shape of the water tower is generally circular. ➢ Take water with a vertical axis pump or a submersible pump.	➢ A raw water intake pipe is extended from the inside of the bank to the river side, and the river water is conducted by gravity flow to a water chamber installed underground inside the bank and pumped up to WTP.
Intake performance	➢ If a water depth of 2 m or more is secured, stable water intake is possible even if there are large fluctuations in the water level. ➢ High economic advantage especially in the case of large amount of water intake. ➢ Generally used for large rivers	➢ It is necessary to plan a water absorption tank that secures the required water depth so that water can be taken at low water levels or lower. ➢ A mud drain pit is required in the water absorption tank for stable water intake.
Workability	➢ It is necessary to bring in heavy objects such as management bridges. ➢ Underwater construction requires temporary construction for water stoppage at the time of construction, but if the foundation ground is rock, it will be difficult to place sheet piles for water stoppage. ➢ A long-span management bridge is required, and intermediate piers need to be installed on the slope of the embankment.	➢ It is necessary to construct a chamber for collecting water inside the bank. ➢ Excavation inside the existing embankment is required for the construction of the catchment chamber inside the embankment and the laying of the intake pipe to the water's edge. ➢ Construction of the opening involves some underwater construction
Environmental impact	➢ It interferes with shipping.	➢ Extensive excavation is required on the embankment side. ➢ No interference with shipping
Maintenance	➢ The structure itself has a long life. ➢ Required regular maintenance of the raw water pump. ➢ Need to remove sediment or sludge from the intake chamber.	➢ Regular maintenance of the raw water pump is required. ➢ Maintenance such as removal of dust and sand in the water collection pipe is required.
Economical	Medium	Medium

Note: Above mentioned photos and drawings are just examples.
Source: JICA Data Collection Survey Team

Table 6.2.2 Basic Elements of Different Raw Water Intake Method (2/2)

Item	Inclined Pipe	Vertical Wall Gate with Intake Channel
Example photo		
Example drawing		
Outline of facilities	➢ A raw water intake pipe is extended in the direction of the river along the slope of the embankment and water is taken by a submersible pump installed at the end of the intake pipe.	➢ It is a structure in which the raw water intake pipe is replaced with an open channel structure in "Intake Tower with Extended Pipe". ➢ A concrete structure consisting of a pump room and a conduction channel will be constructed on the revetment, and stable water intake will be performed from the openings provided according to different water levels.
Intake performance	➢ Possible to cope with large fluctuations in water level. ➢ Necessary to install a submersible pump while ensuring the required depth for low water level (LWL) to ensure stable water intake. ➢ Generally used for medium volume intake.	➢ An open channel provided instead of the water intake pipe make it easy to remove sludge and sediment and to keep stable water intake.
Workability	➢ The size of the structure body and foundation structure can be made relatively small. ➢ Necessary to construct a revetment to prevent scouring on the upstream and downstream sides of the structure. ➢ Partial underwater construction is required for construction of intake chamber, etc.	➢ To conduct raw water through a concrete culvert, the scale of drainage work, revetment protection work will increase. ➢ Necessary to construct a revetment to prevent scouring on the upstream and downstream sides of the structure. ➢ Draining work is indispensable when constructing a water collection channel.
Environmental impact	➢ Since the pump body is underwater, the shed structure can be downsized. ➢ No interference with shipping	➢ The concrete structure will be larger than "Intake Tower with Extended Pipe", which will affect the surrounding environment. ➢ No interference with shipping.
Maintenance	➢ Required regular maintenance of the raw water pump. ➢ Need to remove sediment or sludge from the intake chamber.	➢ Easy to clean the conduction open channel and large advantage of maintainable ➢ Required maintenance such as removal of dust and sand in the pump water absorption chamber.
Economical	Small	More expensive than Intake Tower with Extended Pipe

Note: Above mentioned photos and drawings are just examples.
Source: JICA Data Collection Survey Team

It is necessary to determine the raw water intake facility by comprehensively considering the location conditions of the WTP to be constructed in the future, the water source to be taken in, the revetment situation, the cost of water conduction, etc.

On the other hand, there are existing WTPs and raw water intake facilities around the raw water intake facility that are scheduled to be newly constructed this time, and there is already a track record of stable operation. Therefore, in this study, the JICA Data Collection Survey Team proposes the recommended raw water intake form and structure as follows, based on the above comparative study and the cases of similar facilities. However, it is necessary to adopt the desired structure after confirming the basic design conditions such as river longitudinal survey and ground survey at the design stage.

The currently recommended raw water intake methods are summarized below. In the case of Khsach Kandal, there are scattered points that are candidates for raw water intake, and JICA Data Collection Survey Team assumed a raw water intake pipe type that is advantageous in terms of cost for small-scale raw water intake.

However, if the riverbank at the final raw water intake point has a nearly vertical shape, the vertical wall gate with intake channel similar to Ta Mouk will also be considered.

Table 6.2.3 Recommended Type of Raw Water Intake Structure

Item	Bakheng Phase II Intake Nirodh Intake Koh Norea Intake Khsach Kandal Intake	New Airport City Intake	Ta Mouk Intake
Water source	Mekong River	Bassac River	Sap River
Recommended Type	Intake Tower with Extended Pipe		Vertical Wall Gate with Intake Channel
Reason	➢ In the catchment pipe type, the extension distance of the catchment pipe can be shortened as the water level rises, so that the hindrance to boat transportation can be minimized. ➢ - The same method is adopted at the water intake facility constructed in the river, and stable operation management is realized.		➢ Since it is not the main route for ship transportation, there is no problem in constructing an intake culvert in the river. ➢ Easy maintenance because water can be conducted through an open channel.

Source: JICA Data Collection Survey Team

(3) Revetment and Riverbed Protection at the Raw Water Intake Point

1) Raw Water Intake Facilities of Bakheng Phase III

The proposed raw water intake facility candidate site is a riverbank that is almost in a natural state. Appropriate revetment work and riverbed protection work should be implemented to realize stable facility maintenance.

A concrete wall will be installed as a revetment and the masonry will be filled with mortar. In the area below the minimum water level, masonry will be carried out as a riverbed protection work.

The outline of the proposed construction is shown in ***Figure 6.2.10*** and ***Figure 6.2.11***. It is assumed that the cross section is almost the same as the result investigated at the time of design stage of the raw water intake facilities for Bakheng Phase I and Phase II. However, since the river cross-sectional shape differs locally depending on the flow conditions, it is necessary to carry out river cross-sectional survey at the time of design.

Figure 6.2.10 Current Situation of Candidate Site of Raw Water Intake for Bakheng Phase III

Source: Photo taken by PPWSA on Dec 27, 2020

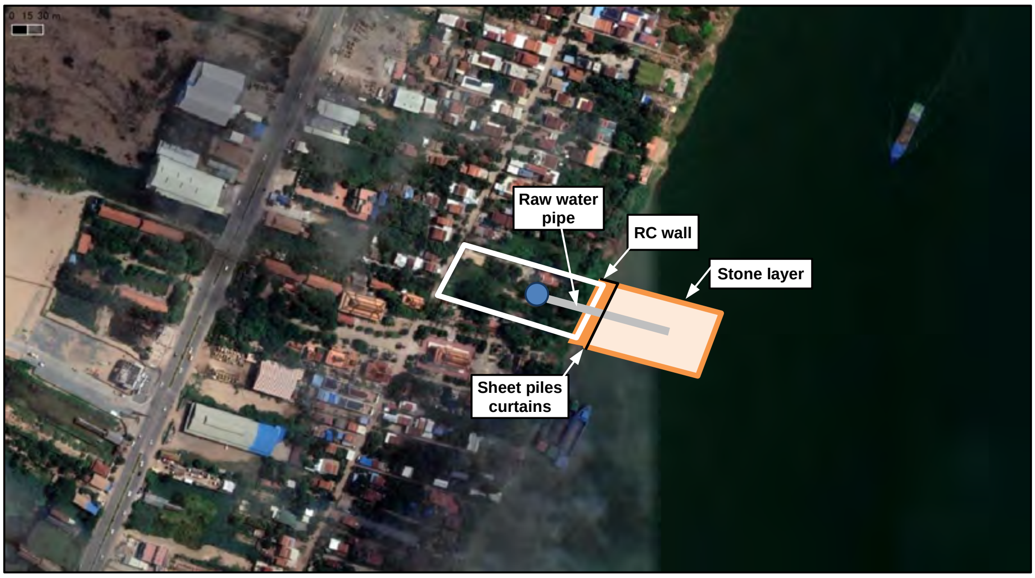


Figure 6.2.11 Outline Plan of Proposed Protection Of Revetment and Riverbed for Bakheng Phase III

Source: JICA Data Collection Survey Team

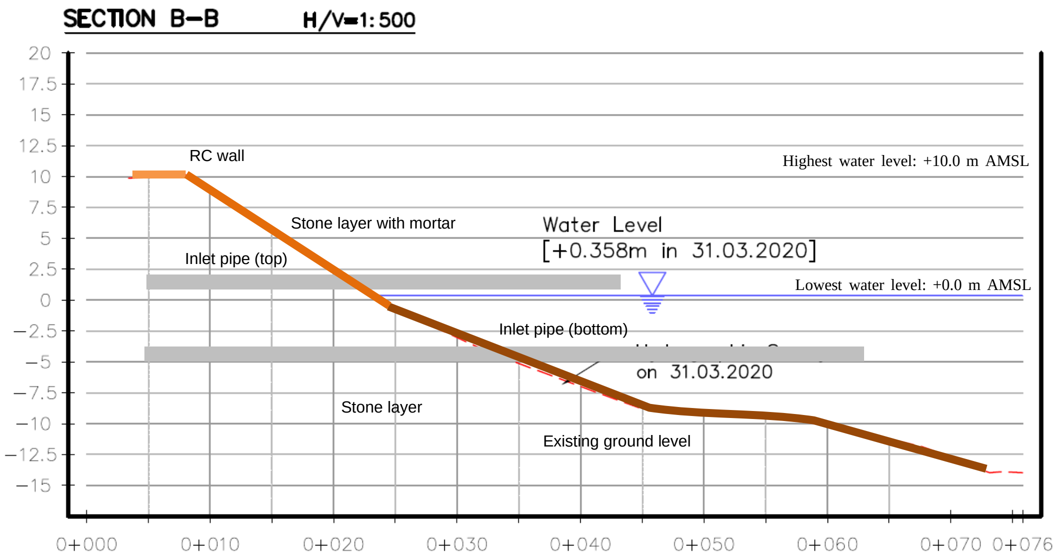


Figure 6.2.12 Outline Section of Proposed Protection of Revetment and Riverbed for Bakheng Phase III

Source: Data in JEB Survey & Engineering (WOWO) modified by JICA Data Collection Survey Team

2) Raw Water Intake Facilities of Nirodh and Koh Norea

It is assumed that a revetment made of concrete will be installed to protect the reclaimed site from the flow of the Mekong River, but at present, the revetment material and cross-sectional shape have not been clarified.

Both Nirodh and Koh Norea raw water intake facilities are expected to be constructed inside of the Koh Norea revetment area. Therefore, the revetment work of the raw water intake facility needs to be improved according to the revetment of Koh Norea. Since the details of the revetment embankment are unknown at this time, it is desirable to consider revetment work with concrete and mortar-filled masonry as needed. In addition, it is desirable to masonry as a riverbed protection work in the area below the minimum water level.

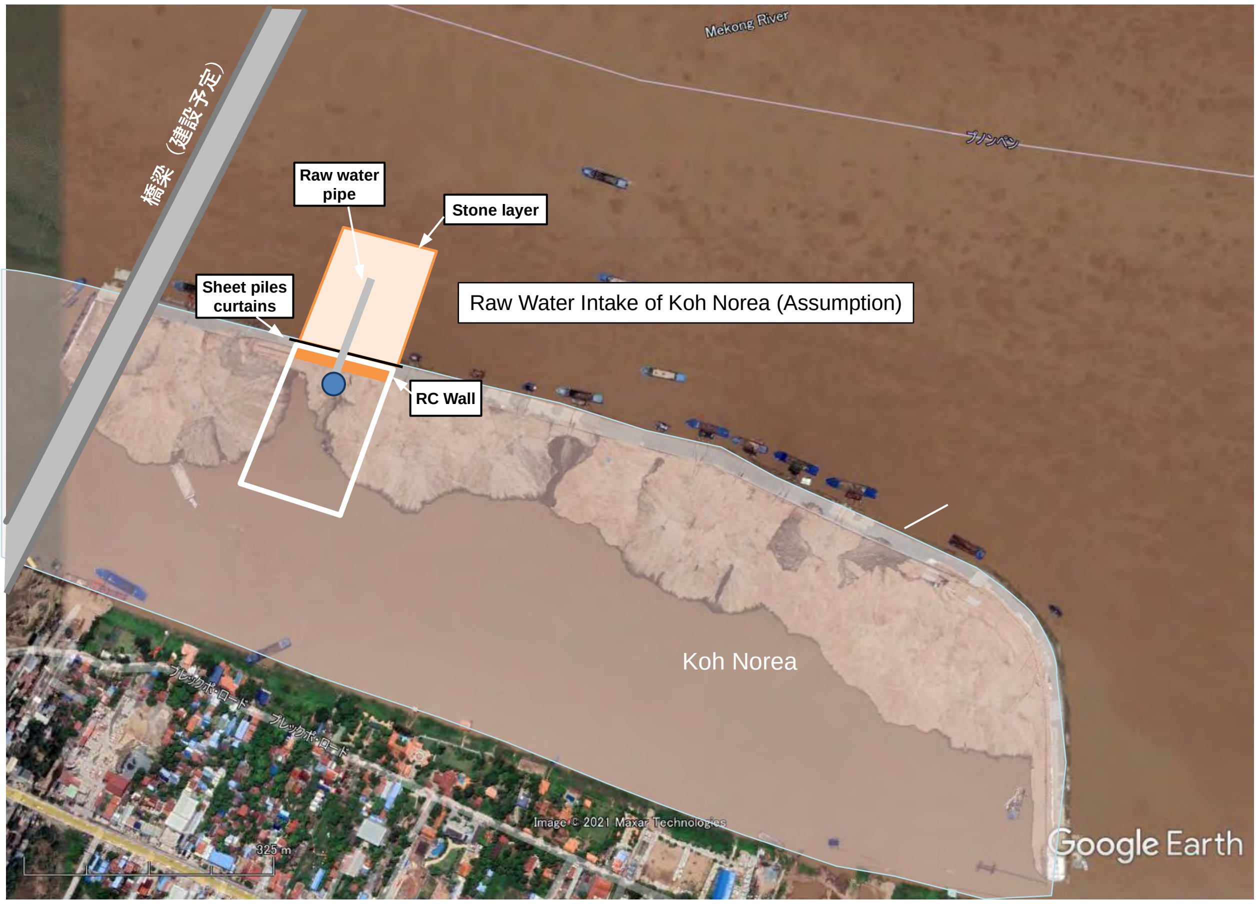


Figure 6.2.13 Outline Plan of Proposed Protection of Revetment and Riverbed for Nirodh Phase III and Koh Norea

Source: JICA Data Collection Survey Team

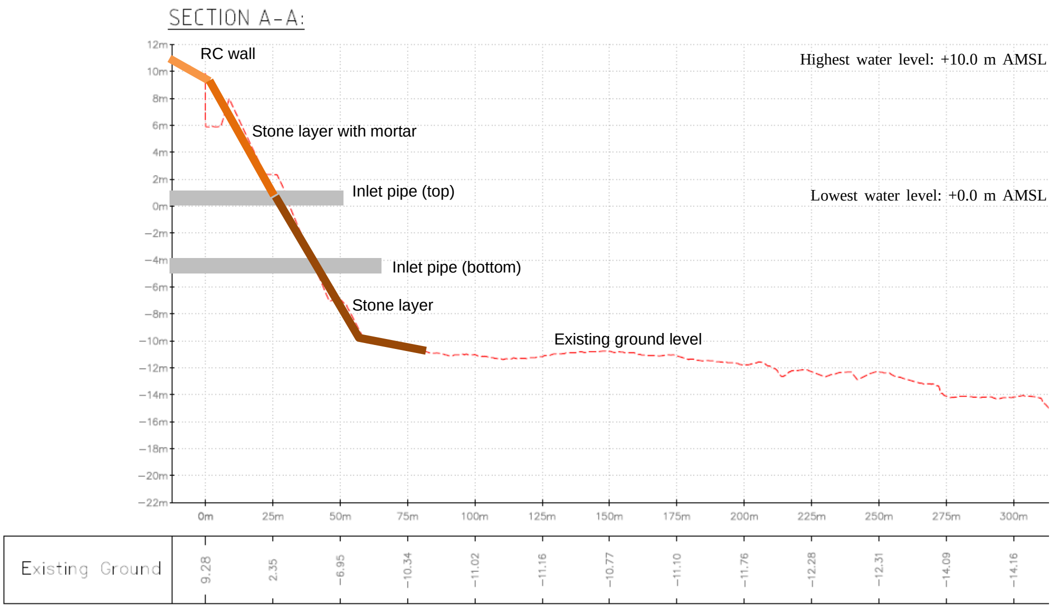


Figure 6.2.14 Outline Section of Proposed Protection of Revetment and Riverbed for Nirodh Phase III and Koh Norea

Source: Data in JEB Survey & Engineering (WOWO) modified by JICA Data Collection Survey Team

According to the references shown in ***Figure 6.2.15*** below, the area near the Nirodh area of the Mekong River is the place where riverbed scouring had progressed before the reclamation. Since there is a high possibility that the flow will change due to future reclamation and the moat, riverbank erosion, and sedimentation conditions around this area, including the opposite bank, will change. Must be considered.

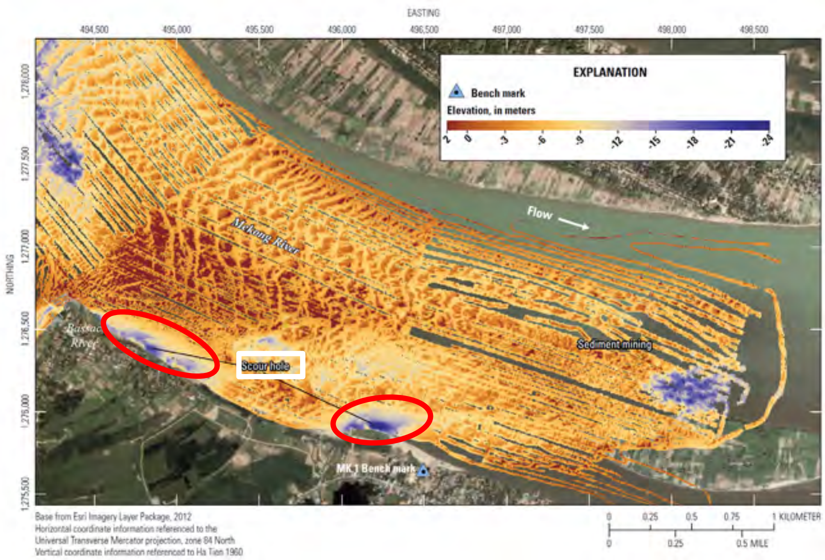


Figure 6.2.15 State of Cross Section of Mekong River Channel Before Reclamation

Source: USGS, Hydrographic Survey of Chaktomuk, the Confluence of the Mekong, Sap, and Bassac Rivers near Phnom Penh, Cambodia, 2012

3) Raw Water Intake Facilities of Ta Mouk

Regarding the Ta Mouk raw water intake facility, JICA Data Collection Survey Team proposes a candidate site on the right bank of the Sap River, which is located about 21 km upstream from the confluence of the Mekong River. Since neither the river channel cross-section data nor the bathymetry results near the candidate site of the Ta Mouk intake facility were available, this proposal is based on the survey results of the Phum Prek intake facility. The Phum Prek intake facility is located about 18 km downstream from the Ta Mouk intake facility candidate site, but it is assumed that the river cross sections are similar at this time.

Figure 6.2.16 Current Situation of Candidate Site of Raw Water Intake for Ta Mouk

Source: Photo taken by PPWSA on Oct 01, 2021

Figure 6.2.17 Outline Plan of Proposed Protection of Revetment and Riverbed for Ta Mouk
Source: JICA Data Collection Survey Team

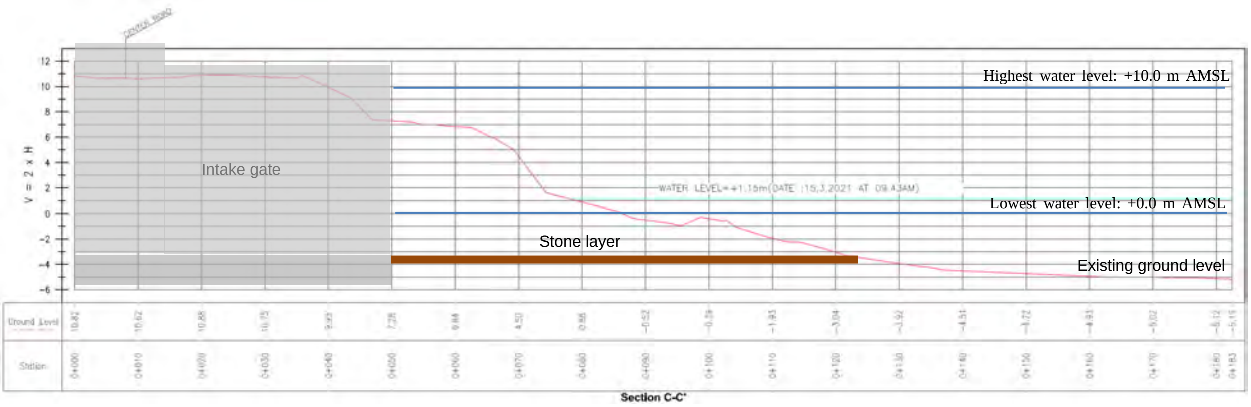


Figure 6.2.18 Outline Section of Proposed Protection of Revetment and Riverbed for Ta Mouk
Source: Data of Cam E.S. Topographical Survey Report modified by JICA Data Collection Survey Team

4) Raw Water Intake Facilities of Khsach Kandal

The candidate site for the Khsach Kandal raw water intake facility is located on the left bank of the Mekong River, about 5 km upstream from the confluence of the three rivers and is less developed than the left bank side. The riverbank is almost in a natural state, the revetment has not been maintained, and the cross section of the river channel and the riverbed condition on the left bank side are unknown. It is necessary to adopt appropriate revetment work and riverbed protection work so that the structure will be desirable after conducting cross-river surveys and ground surveys.

5) Raw Water Intake Facilities of New Airport City

Neither the cross section nor bed condition of the river channel on the right bank of the Bassac River near the candidate site for the New Airport City raw water intake facility are known. The riverbank is almost in a natural state, and the revetment is not maintained. It is necessary to adopt appropriate revetment work and riverbed protection work so that the structure will be desirable after conducting cross-river surveys and ground surveys.

(4) Temporally Specifications for Raw Water Intake Facilities

In Chapter 5, the location and natural conditions (riverbank, water level, flow rate, etc.) of each water source candidate point are organized. Based on this, the specifications of the raw water intake facilities at each point were organized as follows, taking into consideration the similarities in the scale of the existing and under-construction intake facilities.

The main operational restrictions of the raw water intake facility that should be defined in the specifications are as follows:

- Installation of a protective device at the tip of the raw water intake pipe to prevent the intrusion of large foreign substances.
- Installation of a screen with an automatic removal device to prevent foreign matter made of plastic or rubber from entering.
- Setting the pump capacity considering the pressure loss in the headrace.
- The pump water absorption well is divided into two tanks so that it can be operated with 50% of the water intake capacity even during maintenance of the pump.
- When adopting a vertical supercritical pump, the shape of the suction port should be open or semi-open so that the impeller will not be damaged even if foreign matter is mixed in.
- Having a mud drainage function that can appropriately remove the sediment accumulated at the bottom of the pump water absorption well after water collection.
- Permanent installation of hoist cranes for installation and relocation of pump equipment.
- Being secured sufficient ventilation capacity, especially electrical equipment should be installed in another adjacent building.
- Install VFD to separate heat source. This makes it possible to easily control a plurality of pumps from the same room.
- As a cost-saving measure, power is supplied to the lighting inside the pump room and inside the venue by solar power generation.
- The design HWL shall be defined as the maximum water level in the past (estimated value at the facility location). Due to the effects of climate change and upstream dam development and operation, the annual maximum water level (in average) will decrease. However, the largest forecast shows that the annual maximum water level will increase (compared to the current situation) in some years. Measures against flooding of electrical machinery and equipment (such as securing the installation height of equipment) should be taken.

1) Raw Water Intake Facilities of Bakheng Phase III

Table 6-2.5 shows the proposed components of the new raw water intake facility corresponding to Phase III of the Bakheng WTP.

Table 6.2.4 Principal Components of Intake Facilities for Bakheng Pase III

ITEMS	DESCRIPTION
Type of Intake	Intake Tower with Extended Pipe
Target year of construction	Main Structure: 2027 Pump facilities: 2027 (Phase III)
Design intake rate	204,750 m^3/day (Projected production volume 195,000 m^3/day with 5% of water loss)
Design water level	HWL: +10.80 m AMSL, LWL: +0.30 m AMSL (Estimated)
Type of pump	Vertical shaft type mixed flow pump
Suction pipe	Ductile Iron Pipe DN500mm
Pumping capacity	Q=2,200 m^3/hr (per 1 unit)
Number of pump unit	6 units (4 for operation and 2 for stand-by)
Opening for water intake	2 (1 for HWL, 1 for LWL) Electrically operated rectangular gate Extended intake pipe: DN1600 x 2 lines
Complementary equipment	Electrical hoist crane (6 ton), Water level gauge

Source: JICA Data Collection Survey Team

2) Raw Water Intake Facilities of Nirodh and Koh Norea

Regarding water intake for Nirodh WTP (Phase III), it is desirable to expand the raw water intake to a scale that can secure future raw water intake when relocating the raw water intake facility for the existing plants (Phase I & II).

Table 6.2.5 shows the proposed components of the new raw water intake facility corresponding to the Koh Norea WTP.

Table 6.2.5 Principal Components of Intake Facilities for Koh Norea

ITEMS	DESCRIPTION
Type of Intake	Intake Tower with Extended Pipe
Target year of construction	Main Structure: 2029 Pump facilities: 2029
Design intake rate	157,500 m^3/day (Projected production volume 150,000 m^3/day with 5% of water loss)
Design water level	HWL: +10.000 m AMSL, LWL: +0.000 m AMSL
Type of pump	Vertical shaft type mixed flow pump
Suction pipe	Ductile Iron Pipe DN 500 mm
Pumping capacity	Q=1,650 m^3/hr (per 1 unit)
Number of pump unit	6 units (4 for operation and 2 for stand-by)
Opening for water intake	2 (1 for HWL, 1 for LWL) Electrically operated rectangular gate Extended intake pipe: DN 1600 mm x 2 lines
Complementary equipment	Electrical hoist crane (6 ton), Water level gauge

Source: JICA Data Collection Survey Team

3) Raw Water Intake Facilities of Ta Mouk

Table 6.2.6 shows the proposed components of the new raw water intake facility corresponding to the Ta Mouk WTP.

Table 6.2.6 Principal components of Intake Facilities for Ta Mouk

ITEMS	DESCRIPTION
Type of Intake	Vertical Wall Gate with Intake Channel
Target year of construction	Main Structure: 2030 Pump facilities: 2030 (Phase I) / 2031 (Phase II)
Design intake rate	420,000 m^3/day (Phase I: 210,000 m^3/day, Phase II: 210,000 m^3/day) (Projected production volume 200,000 m^3/day with 5% of water loss)
Design water level	HWL: +10.200 m AMSL, LWL: +0.300 m AMSL
Type of pump	Vertical shaft type mixed flow pump
Suction pipe	Ductile Iron Pipe DN500 mm
Pumping capacity	Q=2,200 m^3/hr (per 1 unit)
Number of pump unit	Phase I: 6 units (4 for operation and 2 for stand-by) Phase II: 6 units (4 for operation and 2 for stand-by)
Opening for water intake	3 (1 for HWL, 1 for MWL, 1 for LWL) x 2 pits x 2 units Electrically operated rectangular gate
Complementary equipment	Electrical hoist crane (6 ton), Water level gauge

Source: JICA Data Collection Survey Team

4) Raw Water Intake Facilities of Khsach Kandal

Table 6.2.7 shows the proposed components of the new raw water intake facility corresponding to the Khsach Kandal WTP.

Table 6.2.7 Principal Components of Intake Facilities for Khsach Kandal

ITEMS	DESCRIPTION
Type of Intake	Intake Tower with Extended Pipe
Target year of construction	Main Structure: 2030 Pump facilities: 2030
Design intake rate	105,000 m^3/day (Projected production volume 100,000 m^3/day with 5% of water loss)
Design water level	To be confirmed at the time of design stage
Type of pump	Vertical shaft type mixed flow pump
Suction pipe	Ductile Iron Pipe DN500 mm
Pumping capacity	Q=1,100 m^3/hr (per 1 unit)
Number of pump unit	6 units (4 for operation and 2 for stand-by)
Opening for water intake	2 (1 for HWL, 1 for LWL) Electrically operated rectangular gate Extended intake pipe: DN1600 mm x 2 lines
Complementary equipment	Electrical hoist crane (6 ton), Water level gauge

Source: JICA Data Collection Survey Team

5) Raw Water Intake Facilities of New Airport City

Table 6.2.8 shows the proposed components of the new raw water intake facility corresponding to the New Airport City WTP.

Table 6.2.8 Principal Components of Intake Facilities for New Airport City

ITEMS	DESCRIPTION
Type of Intake	Intake Tower with Extended Pipe
Target year of construction	Main Structure: 2030 Pump facilities: 2030
Design intake rate	31,500 m^3/day (Projected production volume 30,000 m^3/day with 5% of water loss)
Design water level	To be confirmed at the time of design stage
Type of pump	Vertical shaft type mixed flow pump
Suction pipe	Ductile Iron Pipe DN250 mm
Pumping capacity	Q=450 m^3/hr (per 1 unit)
Number of pump unit	4 units (3 for operation and 1 for stand-by)
Opening for water intake	2 (1 for HWL, 1 for LWL) Electrically operated rectangular gate Extended intake pipe: DN800 mm x 2 lines
Complementary equipment	Electrical hoist crane (6 ton), Water level gauge

Source: JICA Data Collection Survey Team

(5) Responding to Issues Related to Raw Water Intake Facilities

In the existing raw water intake facility, the adhesion of shellfish to the water intake pipe has become a problem, and there is a possibility that water intake failure may occur.

At present, there are no proposals for countermeasures from affiliated companies (hearing from PPWSA), and it is necessary to plan and design in advance the countermeasures for such problems that are expected to occur in the future at newly constructed water intake facilities.

According to the staff of Nirodh and Chamcar Mon intake facilities, shellfish are adhering to and multiplying inside the intake pipe and on the wall surface of the shaft. Nirodh carries out removal and cleaning once a year, which is a burden on facility maintenance.

- Frequency of cleaning
  Once or twice per year (according to the situation)
- Cleaning season
  Dry season
- Manpower
  Approximately 10 staffs
- Necessary duration
  Between 4 and 5 hours per cleaning (from 9 am to 4 pm)
- Cleaning method
  Stop the pump, enter the tower chamber, remove the sludge and sediment manually
- Accumulated shellfish
  2 cm of total length

Figure 6.2.19 Shellfish attached inside the chamber of intake tower
Source: JICA Data Collection Survey Team

Similar problems of shellfish (Limnoperna fortunei) adhesion occur mainly in agricultural irrigation facilities in Japan, and measures taken are summarized. Unless a detailed investigation is conducted, it is not known whether or not the shellfish found in the PPWSA facility are of the same species, but since they have characteristics similar to those of Limnoperna fortunei, it is considered useful to know the control method.

Table 6.2.9 Characteristics of Limnoperna Fortunei

Items	Description
Scientific name	Limnoperna fortunei
English name	Golden Mussel
Origin	East Asia, Eastern-Southern Asia
Size	2 or 3 cm
Lifespan	2 or 3 years
Feed	Floating suspension (phytoplankton, etc.)
Breeding season	When the water temperature exceeds 21 ℃
Condition of habitat	Freshwater area (not distributed in brackish water area due to low salt tolerance). It secretes a fibrous substance called byssus and sticks to the adhesion base (concrete, rock, stone, etc.).
Predator	In Japan, cyprinid fish, bluegill, etc.

Source: Manual of damage countermeasure manual 2013, Ministry of Agriculture, Forestry and Fisheries in Japan

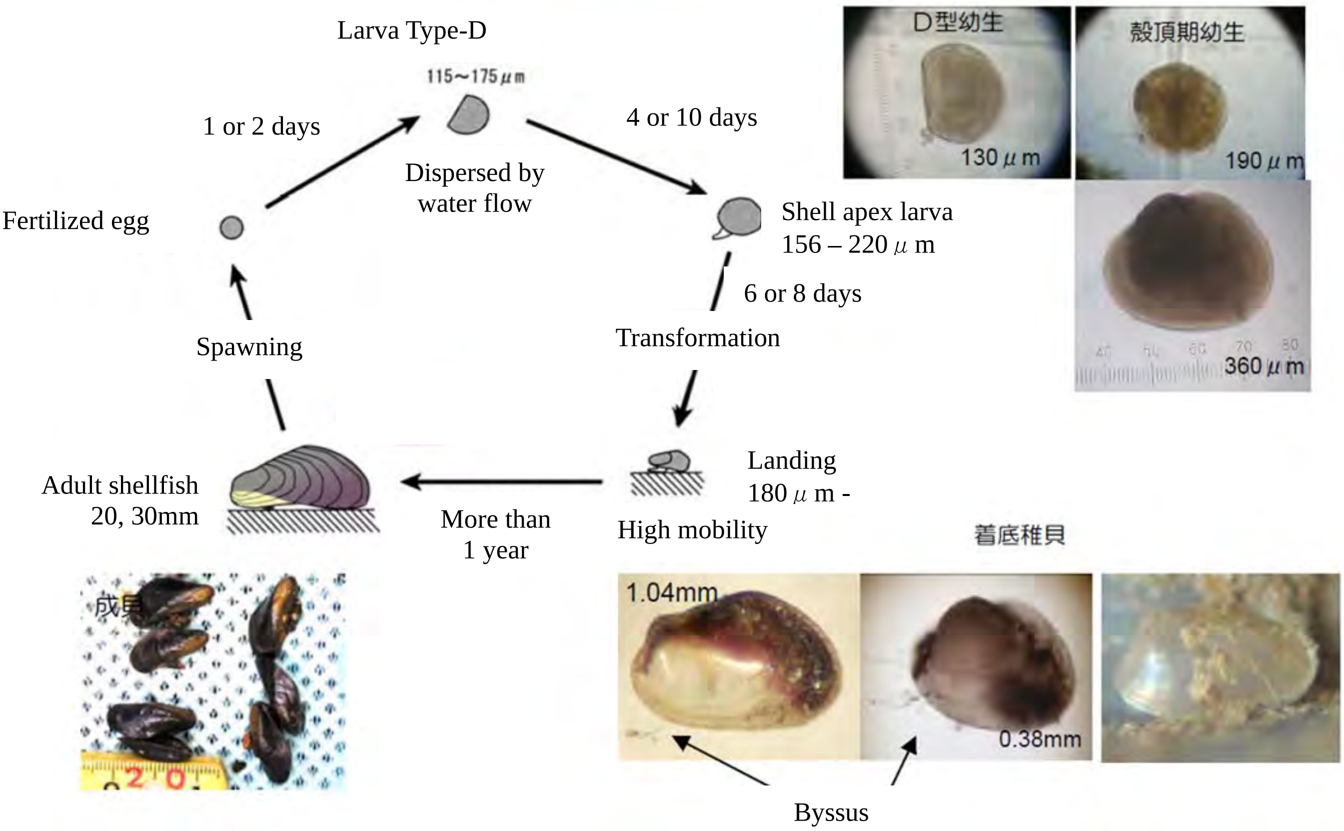


Figure 6.2.20 Genaral Lifecycle of Limnoperna Fortunei (in Japan)

Source: Manual of damage countermeasure manual 2013, Ministry of Agriculture, Forestry and Fisheries in Japan

In the case of Japan, the attaching characteristics of shellfish are organized as shown in ***Table 6.2.10***. There is a possibility that growth will proceed arounds the seams of the beams. In the water intake facility, it is presumed that the following places are structurally easy for shellfish to accumulate.

Table 6.2.10 Place Where Shellfish are Likely to Accumulate

Accumulation characteristics	*Applicable place in intake facility*
Floating larval individuals flow in and settle. Move and group while selecting a preferred location. Environment where objects are likely to accumulate - Environment with many contact surfaces - Dark Environment --The part where the flow velocity is low Since larvae are always present in warm places, shellfish breed multiple times a year. Shellfish die after a 2-3 year accumulation period. Accumulation of carcasses can lead to blockages and obstruction of distribution.	Inner wall of intake tower and corner of water channel - Inner wall of suction pit - Bottom of suction pit - Inner wall of intake/conduction channel - Bottom of intake/conduction channel Joint of wall and pipe - Inner wall of intake pipe - Inner wall of conduction pipe

Source: Manual of damage countermeasure manual 2013, Ministry of Agriculture, Forestry and Fisheries in Japan

It is necessary to consider methods for preventing and removing shellfish growth based upon the actual accumulation characteristics and especially after investigating the temporal characteristics.

It is important to verify the applicability in order to concretely show measures to reduce the growth of shellfish and reduce the management burden. In particular, it is desirable to thoroughly investigate the life cycle of the shellfish, workability, impact on the surrounding environment, maintenance after countermeasures, etc.

Table 6.2.11 shows the main control methods for shellfish. Considering the characteristics and applicability of the water intake facility, it is considered realistic and low cost to combine the following two methods.

- Kill shellfish growth by injecting chlorine

- Physically remove by human power

At present, extreme shellfish growth and accumulation that causes obstruction has not occurred. But monitoring should be carried out at an appropriate frequency to confirm whether shellfish growth is progressing.

Table 6.2.11 Removal Method of Fixed Shellfish

Type	Measures	Description	Applicability
[Preventive measure] Prevention before accumulation of shellfish	Use of materials that prevent fixing	Lining, fixing of silicone paint, change of pipe material (e.g., Copper).	Middle
	Removal with trap	Removal of re-growth shellfish with trap.	Middle
[Postvention measure] Removal of shellfish after accumulation	Chlorine injection Heated water	Killing process of floating shellfish inside the tower and pit.	High
	Drying	Lower the water level to dry the shellfish. Physical removal is necessary afterward.	Middle
	Physical removal	Removal by manpower with scraper.	Low

Source: JICA Data Collection Survey Team

(6) Summary of Proposal for Raw Water New Intake Facilities

Table 6.2.12 summarizes the proposals for raw water intake facilities among the water supply facilities that PPWSA should develop by 2030 to meet the increasing water demand in Phnom Penh.

Table 6.2.12 Summary of Proposed Raw Water Intake Facilities

Name of intake	Location of intake	WTP	Projectet intake flow rate	Area (ha)	Type of intake	Distance to WTP	Target year of construction	Remark
Bakheng 3	Mekong river (right bank), Bakheng area	Bakheng Phase III	204,750	0.5	Type 1*1	2.1	2027	New construction on the PPWSA's land
Nirodh	Mekong river (right bank), Nirodh area inside Koh Norea	Nirodh Phase III	136,500	Not determined yet	Not detemined yet	2.8	2029	Construction together with displacement of existing facility
Koh Norea		Koh Norea	157,500	2.0	Type 1*1	Same location of WTM	2029	Construction integrally both of Intake and WTP facilities
Ta Mouk	Sap river (right bank), Preak Prov area	Ta Mouk Phase I	210,000	0.5	Type 2*2	8.3	2030	Land acquisition will be necessary Construct both of phase I and phase II intake facilities integrally Construct phase III facility in the future
		Ta Mouk Phase II	210,000				2031	
Khsach Kandal	Mekong river (left bank), Khsach area	Khsach Kandal	105,000	0.4	Type 1*1	0.5	2030	Construction integrally both of Intake and WTP facilities
New Airport City	Bassac river (right bank), Setbou area	New Airport City	31,500	0.3	Type 1*1	0.45	2030	Construction integrally both of Intake and WTP facilities

*Type 1: Intake Tower with Extended Pipe
*Type 2: Vertical Wall Gate with Intake Channel
Source: JICA Data Collection Survey Team

6.2.2 Raw Water Transmission Mains

(1) Basic Condition

Table 6.2.13 shows a list of planned expansions and new water purification facilities and their expansions and new water intake facilities until 2030.

Table 6.2.13 WTPs under Construction, Planning for Expansion and New Construction

WTP	Phase		Completion Year	Capacity （m^3/d）	Water Source
Bakheng	Expansion	Phase III	2027	195,000	Mekong
Nirodh	Expansion	Phase III	2029	130,000	Mekong
Koh Norea	New	Full	2029	150,000	Mekong
Ta Mouk	New	Phase I	2030	200,000	Sap
New Airport City	New	Full	2030	30,000	Basac
Khsach Kandal	New	Full	2030	100,000	Basac
Ta Mouk	Expansion	Phase II	Future	200,000	Sap

Source: JICA Data Collection Survey Team

Following raw water transmission mains will be required for the new and expansion of water treatment plants.

Table 6.2.14 Required Raw Water Tranmission Mains

WTP	Capacity (m^3/d)		Intake Location	Main Pipeline Route
Bakheng III	Expansion	195,000	Mekong River, Preak Lieb	National Road 6
Nirodh III	Expansion	130,000	Mekong River, Koh Norea	National Road 1
Koh Norea	New	150,000	Mekong River, Koh Norea	Main road of Koh Norea
Ta Mouk I & II	New	400,000	Sap River, Sangkat Samraong	National Road 5
Khsach Kandal	New	100,000	Mekong River, Kasach Kandal	Intake is closed to the WTP
New Airport City	New	30,000	Bassac River, Setbou	Intake is closed to the WTP

Source: JICA Data Collection Survey Team

(2) Design Criteria

1) Velocity

Velocity of pumping main shall be in the range of 1-3 m/s.

2) Pipe Material

Raw water transmission pipe is quite important facility and reliability is required for the long-term use.
Generally, ductile iron pipe is employed for pipe material for the raw water transmission pipes for the potable water supply and PPWSA have used DCIP in the existing system. Therefore, DCIP is proposed be employed for the pipe material of raw water transmission pipe.

(3) Proposed Raw Water Transmission Mains

Proposed pipelines are shown as follows.

Table 6.2.15 Proposed Raw Water Transmission Mains

WTP	Pipeline Route	Description
Bakheng III		Pipe Material: DCIP Dia.: 1,500 mm Pipeline Length：1.9 km Note: To be installed along National Road 6
Nirodh I & II & III		Pipe Material: DCIP Dia.: 1,100 mm Pipeline Length: 2.7 km Note: To be installed parallelly along existing pipeline along National Road 1
Koh Norea		Pipe Material: DCIP Dia.: 1,350 mm Pipeline Length: 1.0 km Note: Along main road

WTP	Pipeline Route	Description
Ta Mouk I & II		Pipe Material: DCIP Dia.: 2,000 mm Pipeline Length: 7.8 km Note: To be installed crossing National Road 6
Khsach Kandal		Note： Intake site is closed to the WTP site
New Airport City		Note： Intake site is closed to the WTP site

6.2.3 WTP

(1) Planning Policy for Water Treatment Facilities

Aspects to be considered for the planning of the water treatment facility were discussed.

- Location of the water treatment facility
- Capacity of the water treatment facility
- Treatment process of the water treatment facility and sludge treatment facility
- Facility plan for water treatment facilities and sludge treatment facilities
- Layout plan of the water treatment facilities

(2) Proposed Site of Water Treatment Facilities

In planning the water treatment facilities, the following figure shows the existing Nirodh WTP and Bakheng WTP under construction and the Ta Khmao WTP and the Phum Prek WTP (which are being planned with JICA grant aid), and the Koh Norea WTP, Ta Mouk WTP, Khsach Kandal WTP, and the New Airport City WTP (which are scheduled to be constructed in the future).

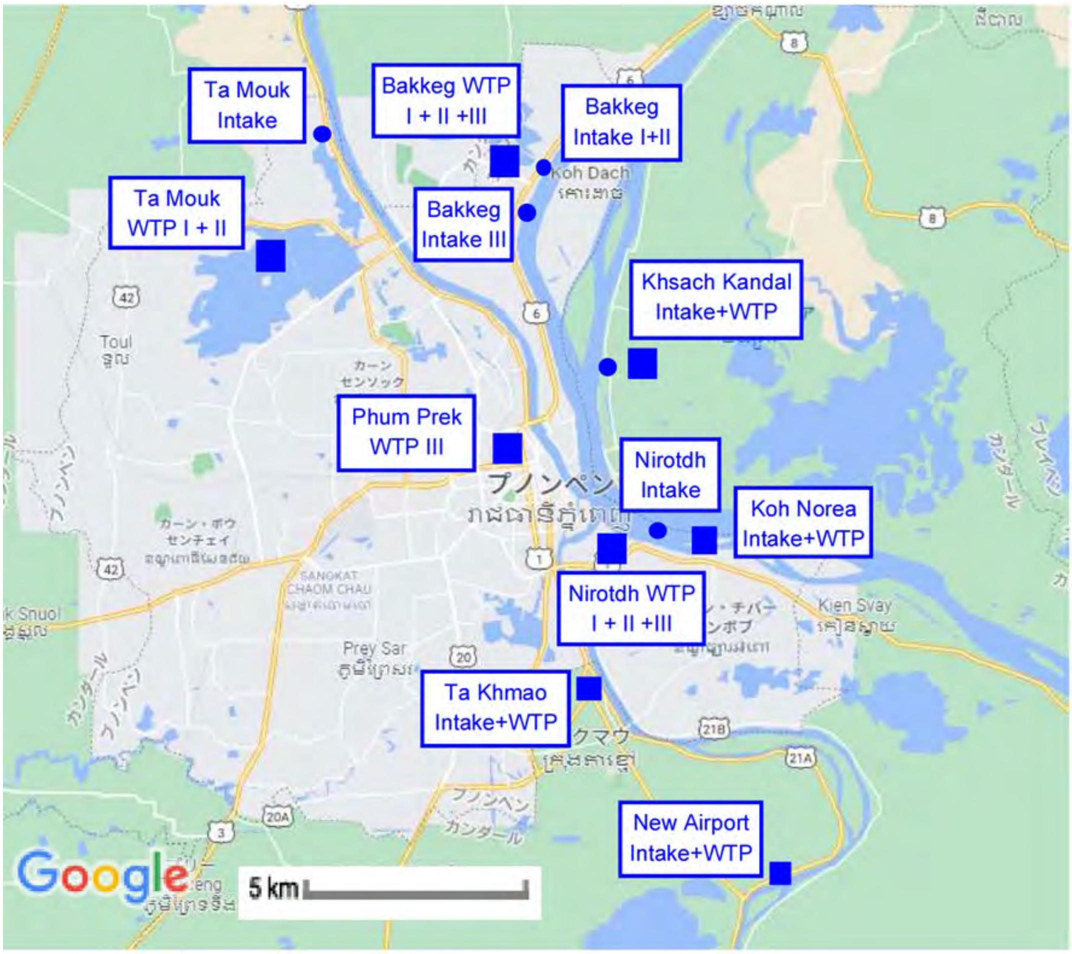


Figure 6.2.21 Location of Future WTPs
Source: JICA Data Collection Survey Team

(3) Capacity of WTPs

Water treatment plants under construction, planning for expansion, and new construction by 2031 are shown in ***Table 6.2.16***.

Table 6.2.16 WTPs under Construction, Planning for Expansion, and New Construction

WTP	Phase	Year Completion	Capacity (m³/d)	Treatment Process	
Immediate Period					
Bakheng	Phase I	2023	195,000	Coagulation/Setting/Filtration	---
Bakheng	Phase II	2023	195,000	Coagulation/Setting/Filtration	---
Intermediate Period					
Ta Khmao	Entire	2024	30,000	Coagulation/Setting/Filtration	---
Phum Prek	Phase III	2026	45,000	Coagulation/Setting/Filtration	---
Bakheng	Phase III	2027	195,000	Coagulation/Setting/Filtration	Thickening/Dewatering
Ultimate Period					
Nirodh	Phase III	2029	130,000	Coagulation/Setting/Filtration	Thickening/Dewatering
Koh Norea	Entire	2029	150,000	Coagulation/Setting/Filtration	Thickening/Dewatering
Ta Mouk	Phase I	2030	200,000	Coagulation/Setting/Filtration	Thickening/Dewatering
Khsach Kandal	Entire	2030	1000,00	Coagulation/Setting/Filtration	Thickening/Dewatering
New Airport City	Entire	2030	30,000	Coagulation/Setting/Filtration	Thickening/Dewatering
Phum Prek	Phase I	2031	(100,000)	Coagulation/Setting/Filtration	Thickening/Dewatering
Ta Mouk	Phase II	2031	200,000	Coagulation/Setting/Filtration	Thickening/Dewatering
		Total	1,270,000		

Source: JICA Data Collection Survey Team

The following items are further studied for the planning of the WTP.

- Outline of the water treatment facility and sludge treatment facility
- Facility plan of the water purification facility and sludge treatment facility
- Layout plan of the water purification facilities

(4) Water Treatment and Sludge Treatment Processes

Soluble components such as odor, color, organic, inorganic substances and by-products of disinfection, and insoluble components such as turbidity, algae and microorganism are to be removed in the treatment process. Process of "Coagulation – Sedimentation – Filtration" is generally used for treating surface water with higher turbidity, and this treatment process is employed.

The type of chemicals to be used and their dosing rates will be decided based on "jar tests" during the detailed design stage. For planning purposes, PAC as a coagulant is considered. Chlorine/Sodium hypochlorite are recommended for disinfection in water distribution networks. In addition, three steps of chlorine injection in treatment process are planned to remove iron/manganese in case if concentration of these elements are high or coagulation process is not able to remove these elements effectively. These considerations result in the treatment process shown in the figure below.

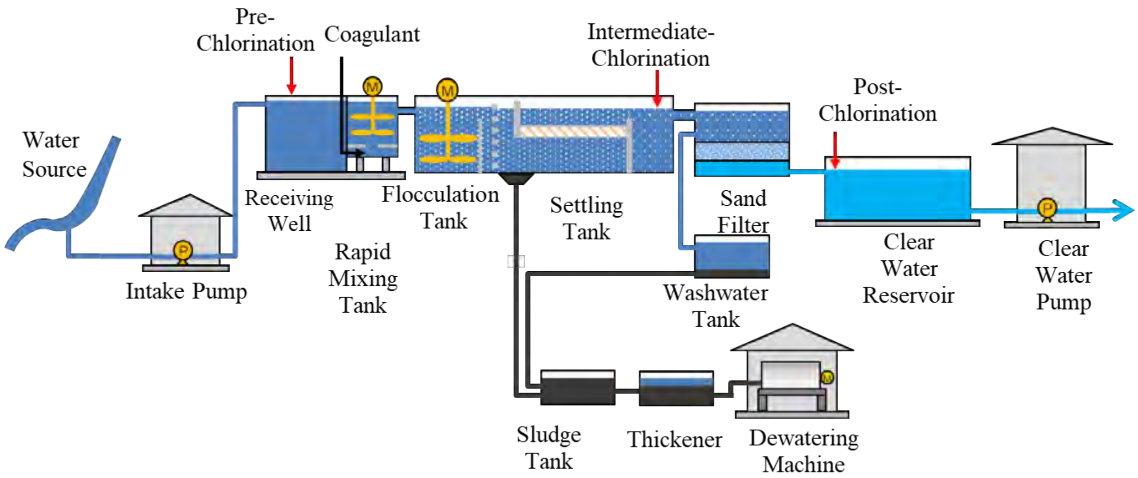


Figure 6.2.22 Water Treatment Process
Source: JICA Data Collection Survey Team

a. Water Treatment Facility

a-1 Receiving Well cum Rapid Mixing Basin

The raw water is to be conveyed by Intake Pump to receiving well. Receiving well and rapid mixing basin is attached to sedimentation basin. Chlorine (as pre-chlorination) and coagulant (PAC) shall be injected, and mixing shall be carried out in the receiving well. Rapid mixing will be achieved by utilizing turbulent flow energy by mechanical mixing because reliable mixture is required for treatment of water with high turbidity.

【Design conditions】

Retention time:	more than 1- 5 minutes
Receiving well:	1.8 minutes
Rapid mixing basin:	1.8 minutes

【Design】

Receiving well:	RC Structure
Rapid mixing well:	RC Structure
Accessories:	Flash mixer, Overflow weir, PAC/Chlorine injection point

a-2 Flocculation Basin

Micro flocs will be produced after injection and rapid mixing of coagulants with raw water. These micro flocs need to be developed into large ones so they will settle more effectively in the sedimentation basin.

The mechanical and non-mechanical flocculation methods, such as horizontal and vertical zigzag flow flocculation methods are commonly used. In this process, a mechanical method in which water from the rapid mixing basin flows to the bottom of the flocculation basin is selected.

【Design conditions】
Retention time: more than 20~40 minutes
【Design】
Basin: RC Structure
Mixing method: Mechanical mixer
Accessories: Vertical mechanical mixer

a-3 Sedimentation Basin

Large flocs formed in flocculation basin are settled in the sedimentation basin. In general, sedimentation basins are categorized into three main types: horizontal-flow basin, horizontal-flow basins with inclined plate or tube settler, and high-speed accelerator (flocculent settling basin).

Horizontal flow with inclined plate and upward flow with tube settler are recommended as sedimentation basin for raw water with wide fluctuation in turbidity. Horizontal-flow sedimentation basins with inclined plates require much maintenance in cleaning when sludge is accumulated on the plates in case of high turbidity raw water. There is high possibility of breaking and falling of inclined plates. Therefore, inclined tube settler should be selected to reduce required land for sedimentation.

Inclined tubes are installed for the purpose of reducing the surface area of the sedimentation basin by accelerating the settling of flocs. The settled sludge at the bottom of the sedimentation tank is collected in several drainage pits and discharged outside the sedimentation tank by periodically opening and closing the drainage valves.

【Design conditions】
Retention time: more than 1 hour
Average flow velocity: 0.4 m/min
Average up-flow velocity: less than 80 mm/min
Surface load: less than 7 to 14 mm/min
【Design】
Basin: RC Structure, up-flow type with tube settler
Sludge discharge valve: Automatic eccentric valve with timer control
Accessories: Inclined tube settler, guiding walls, collecting troughs
de-sludging equipment (valves, pipes)

High-speed coagulation sedimentation basin (flocculent settling basin) is designed to improve the efficiency of coagulation/sedimentation, using existing slurry to form flocs with a mechanical or pulsation, and then separating the supernatant from the descending slurry with an upward water flow. In many cases, a rotary sludge scraper is installed to facilitate the removal of sludge.

【Design conditions】
Retention time: 1 to 2 hours

【Design】
Basin: RC Structure, up-flow type with tube settler
Mixing method: Vertical mixer or pulsation device
Accessories: Sludge collector

a-4 Filter

Micro flocs which cannot be settled down in the sedimentation basins should be separated out in filters. Two-layer filter media of anthracite and sand can be employed. However, filter bed with single filter media (silica sand) with thickness of 1000 mm is applied because many filters are of this type.

Backwashing with surface washing method and backwashing with air scouring method are two filter washing methods. Considering particle diameters likely to be produced in Phonm Penh suburbs, the backwashing with air scouring method is selected. And filtration speed will be reduced to the maximum level of 150 m/day for single filter media (silica sand) filter.

【Design conditions】

Filter flow speed: Less than 200 m/day
Type: Single filter media rapid sand filter

【Design】

Filter: RC Structure
Filter media: Single layer (Silica sand: 1000 mm thickness)
Uniformity coefficient: less than 1.7 mm
Washing method: Air washing + Back washing
Accessories: Air wash equipment (blower), back wash (pump), under drain system
Inlet, outlet and drain valves (electrically driven)

a-5 Clear Water Reservoir

Theoretically, the amount of treated water and treated water pumping should be the same. However, in case that the two flows are not the same, a clear water tank will be required to adjust for the flows difference. The design volume is set as one hour of the daily treatment capacity. Three trains with horizontal-flow mixing by baffle wall are proposed with one injection point per train for post-chlorination.

【Design conditions】

Retention time: More than 1.0 hour of the daily treatment capacity
Mixing method: Horizontal zigzag flow type

【Design】

Reservoir: RC Structure
Accessories: Chlorine injection point, water level gauge, overflow pipe,
drain equipment (pipe and valve) and ventilation

a-5 Clear Water Reservoir

Theoretically, the amount of treated water and treated water pumping should be the same. However, in case that the two flows are not the same, a clear water tank will be required to adjust the flows difference. The design volume is set as one hour of the daily treatment capacity. Three trains with horizontal-flow mixing by baffle wall are proposed with one injection point per train for post-chlorination.

【Design conditions】

Retention time: More than 1.0 hour of the daily treatment capacity
Mixing method: Horizontal zigzag flow type

【Design】

Reservoir: RC Structure
Accessories: Chlorine injection point, water level gauge, overflow pipe,
drain equipment (pipe and valve) and ventilation

a-6 Chemical Dosing Facility

Alum and poly-aluminium chloride (PAC, ACH) are coagulants typically used in the flocculation process at WTPs. PPWSA changed from alum to PAC in 2013 and no alkaline agents such as slaked lime have been used since. Powdered PAC is used in the existing WTPs. The system consists of a dissolution tank, storage tank, and injection pump. The same method will be used for future projects.

a-7 Chlorination Facility

A chlorination facility is required to maintain disinfection of the water distribution pipelines and provide safe water to consumers. Moreover, a three step chlorination process is recommended for iron/manganese removal. Key points related to dosing and purposes are as follows:

- Pre-chlorination: Average dosing rate is set as the minimum rate in order to prevent algae growth and remove iron/manganese based on the result of chlorine demand test.

- Intermediate-chlorination: Removal of iron/manganese and used as an alternative of pre-chlorination when the raw water is polluted by wastewater along the intake canal.
- Post-chlorination: Providing residual chlorine in the finished water to maintain disinfection against potential pollutants seeping into the distribution system.

The chemicals generally used for chlorine disinfection in large WTPs are liquefied chlorine and sodium hypochlorite. Both of these chemicals are often procured from outside sources. Sodium hypochlorite can be generated at the WTP, but it is preferable to purchase it from outside because of the difficulty in operation and maintenance of the generating equipment and the high cost of generation. However, taking into account the risk of a situation where it cannot be purchased from outside, the current policy of MISTI and PPWSA is to generate sodium hypochlorite on-site.

Table 6.2.17 Comparison of Chlorination Sources

Chemical	Liquid Chlorine	Sodium Hypochlorite	
State	Liquid/gas	liquid	liquid
Effective chlorine (%)	99.4	0.8	12.0
Supply	Procurement	On-site generation	Procurement
Cost	Fair	Expensive	Need to find supplier
Operation/maintenance	Little difficult	Difficult	Easy

Source: JICA Data Collection Survey Team

b. Wastewater/Sludge Treatment Facility

In Phnom Penh, wastewater and sludge from the WTPs were previously discharged into the neighbouring canals and rivers, but since the wastewater standards are applied, the wastewater and sludge must conform to the wastewater standards and the sludge must conform to the disposal destination standards.

The wastewater treatment system is determined by taking into consideration the quality of raw water, quantity and quality of wastewater, nature of sludge, disposal method of generated cake, difficulty in maintenance and management, site area, construction cost, etc. The wastewater treatment facility generally consists of drainage basins, sludge drainage basins, and thickening tank, etc. Dewatering facilities such as lagoons, drying beds, and mechanical dewatering machines shall be provided.

In general, there are two major types of dewatering systems: drying beds, which are inexpensive to construct, and mechanical dewatering systems, which do not require large areas. Since it is difficult to obtain large plots of land in Phnom Penh, the mechanical dewatering system will be adopted. All of the waste sludge from the thickening tank is transferred to the mechanical dewatering system, and after dewatering the sludge, it is transported to the disposal site and the supernatant water is discharged into the drainage basin.

b-1 Backwash Wastewater Tank (for backwash wastewater of filter)

Backwash wastewater tanks temporarily store the wastewater from the filters. Its capacity should be determined by considering the amount of backwash water generated per day.

【Design conditions】

Retention time: Two hours of backwash water from filters

【Design】

Reservoir: RC Structure
Accessories: Supernatant water suction float system, drainage pumps, sludge pumps

b-2 Sludge Thickener

Thickening tanks are installed to accelerate the dewatering of sludge and reduce the amount of sludge. Thickening tanks can be broadly classified into three types: gravity type, flotation type, and filtration type. Since gravity type thickeners are generally used in WTPs, gravity type thickeners are used, and rotary rake type thickeners are installed to increase the effect. The sludge accumulated at the bottom is pumped to a mechanical dewatering facility.

【Design conditions】

Retention time: 12 to 24 hours

【Design】

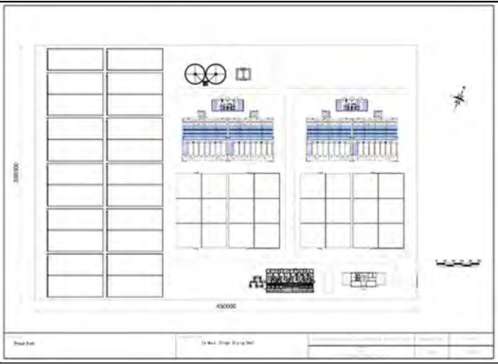
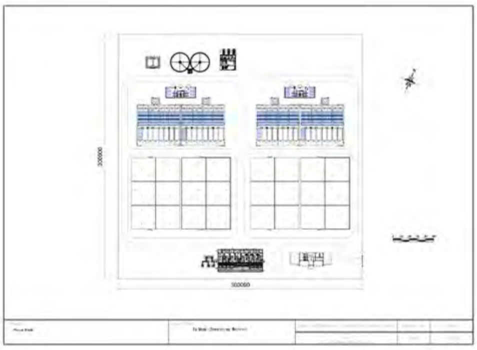
Reservoir: RC Structure

Accessories: Sludge collectors, de-sludge pumps

b-3 Sludge Dewatering Facility

The sludge in the sedimentation tanks and backwash effluent from filters is to increase the sludge concentration in thickening tanks and dewatering facility to facilitate transport and disposal outside the WTP. Dewatering of sludge is done mainly by sun drying and mechanical dewatering by sludge dewatering machines. Both methods are compared below.

Table 6.2.18 Comparison of Sludge Dewatering Methods

Type	Drying Bed	Dewatering Machine
Layout Plan (ex. Ta Mouk WTP)		
Area	WTP 13.5 ha (300 m x 450 m)	WTP 9 ha (300 m x 300 m)
Land	Large land required	Large land not required
Construction Cost	Low cost, mainly civil works	High cost, dewatering machines, polymer dosing
Operation/ Maintenance	No advanced technology, but a lot of manpower is required.	largely automated, not required a lot of manpower, but required advanced technology
Evaluation	Not Applied	Applied

Source: JICA Data Collection Survey Team

Since it is difficult to obtain large plots of land in Phnom Penh and PPWSA cannot invest significant worker hours to sludge treatment, the mechanical dewatering facilities are preferable.

The dewatering equipment is installed to store and dewater the sludge sent from the thickening tank. Dewatering liquid and washing wastewater from the dewatering machine are discharged into the drainage tank by natural flow, and the sludge is removed from the site by truck and disposed of at the disposal site. An access road shall be installed for carrying out the dried sludge. Dewatered sludge will be used off-site as fill material for land development and as soil cover for the disposal site.

【Design】

Sludge Tank: RC Structure

Dewatering Building: Steel-frame Slate Building

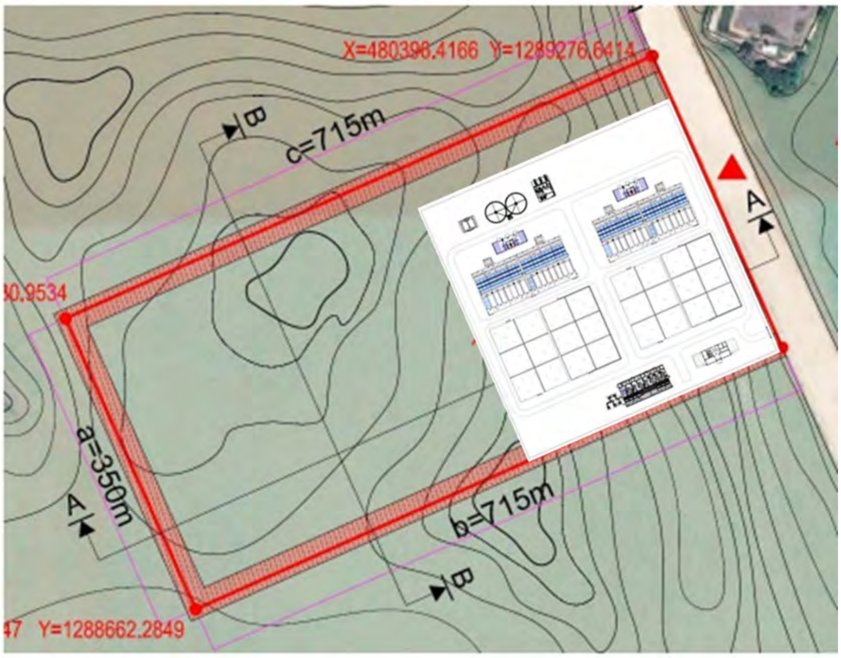
Accessories: Dewatering machines, Polymer dosing system, Sludge pumps

(5) Proposed WTP

Outline of WTPs are shown in ***Table 6.2.19***.

Table 6.2.19 Summary of Proposed WTP

WTP	Layout	Area
Bakheng I + II + III		Capacity: Phase I: 195,000 m^3/d Phase II: 195,000 m^3/d Phase III: 195,000 m^3/d Area: 14.5 ha
Nirodh I + II + III		Capacity: Phase I: 130,000 m^3/d Phase II: 130,000 m^3/d Phase III: 130,000 m^3/d Area: 9.6 ha
Koh Norea		Capacity: 150,000 m^3/d Area: 2.0 ha

Ta Mouk I + II		Capacity: Phase I: 200,000 m^3/d Phase II: 200,000 m^3/d Area: 9.0 ha
New Airport City		Capacity: 30,000 m^3/d Area: 1.1 ha
Khsach Kandal		Capacity: 100,000 m^3/d Area: 1.6 ha

Source: JICA Data Collection Survey Team

(6) Basic Conditions of Proposed WTPs and Sludge Treatment Facilities

a.1 Bakheng WTP Phase III

Name of Water Treatment Plant : Bakkeng III

Capacity	195,000 m^3/d				
Water Source	205,000 m^3/d	Mekong River HHWL = 10.20 m, LLWL = 0.10 m			
Name of Water Treatment Plant :	Bakkeng - 3rd Stage				
Capacity	195,000 m^3/d				
Treatment Process					
1. Rapid Mixing 2. Flocculation 3. Sedimentation 4 Filtration 5 Disinfection					
Receiving Well					
Type	Recutangular				
Retention Time	9.0 sec				
Size & Q'ty	1.4 mW x	11.2 mL x	1.15 mD x	1 unit	
Rapid Mixing					
Type	Mechanical Mixing				
Retention Time	0.9 min				
Size & Q'ty	2.5 mW x	2.5 mL x	5.04 mD x	4 units	
Equipment	Vertical Mixer				
Flocculation					
Type	Mechanical Mixing				
Retention Time	19 min				
Size & Q'ty	6.1 mW x	6.1 mW x	4.29 mD x	16 units	
Equipment	Vertical Mixer				
Sedimentation Tank					
Type	Up-Flow with Lamella Plate (Tube Settler)				
Retention Time	39.2 min,	0.7 hr			
Size & Q'ty	12.5 mL x	6.1 mW x	4.34 mD x	16 units	
Surface Load	110.7 mm/min				
Trough/Pipe	Tube Settler, Orifice Trough				
Sludge Removal	Sludge Extraction Valve (Pneumatic)				
Equipment	Sludge Extraction Valve				
Operation	Sludge Removal - Auto				
Filter					
Type	Gravity, Single Media, Constant Flow, Level Control				
Filtration rate	214 m/d (	8.92 m/hr)	233 m/hr at washing		
Filter Bed Area	75.8 m^2/filter				
Size & Q'ty	5.3 mW x	14.3 mL x	12 filters		
Filter Media	Sand : 1.0 mm x 1000 mm				
Washing Rate	Air Scour : 0.116/0.88	m/min Wash :	0.168 m/min	Rincing :	0.334 m/min
Washing System	Backwashing (1.0 min), Air Scouring + Backwashing (5 + 25 min), Rincing (8 min)				
Wash Trough	7 trough/bed x 2 beds/filter				
Equipment	Inlet Gate, Outlet Valve, Level Control Siphon, Siphon Regulation System				
	Washwater Inlet Valve,Washwater Discharge Gate, Washwater Pump				
	Scour Air Inlet Valve, Air Blower				
Operation	Automatic & Step-by- step				

Chemicals	
Alum	Tank + Mixer : 3 , Dosing Pump : 3
Lime	Tank + Mixer : 3, Lime Pump : 3
Chlorine	Chlorinator -Pre : 3(1), -Post : 3(1)
Clear Water Reservoir	HWL = 12.8 m, LWL = 8.37 m
Reservoir	11,600 m^3 x 2 reservoirs
Clear Water Pump	HWL = 13.2 m, LWL = 8.5 m
Distribution	(1 to 6) 30.0 m^3/min x 53 m x 6 units
Sludge Treatment Facility	Bakkeng - 1nd Stage + 2nd Stage + 3rd Stage
WTP Capacity	585,000 m^3/d
Raw water	Turbidity 210 NTU (asumption for 3 months average in rainy season)
Sludge Treatment Capacity	115.38 ds-ton/d
Treatment Process	
1. Backwash Wastewater Tank 2. Sludge Thickener 3. Dewatering Machine	
Backwash Wastewater Tank	
Type	Recutangular
Retention Time	2.0 hrs x 4 tanks
Size & Q'ty	12 mW x 25 mL x 3.5 mD x 4 units
Sludge Thickener	
Type	Circular
Retention Time	12.0 hrs
Size & Q'ty	16.0 m dia. x 4.0 mD x 2 units
Sludge Dewatering Machine	
Type	Centrifuge
Retention Time	1500 kg-ds/hr x 3 units (includeing 1 unit for standby)
Size	20 mW x 30 mL

Source: JICA Data Collection Survey Team

a.2 Nirodh WTP Phase III

Name of Water Treatment Plant : Nirotdh III

Capacity		130,000 m³/d	
Water Source		135,000 m³/d	Mekong River HHWL = 10.20 m, LLWL = 0.10 m
Name of Water Treatment Plant :		Nirouth - 3rd Stage	
Capacity		130,000 m³/d	
Intake Facilities		Mekong River	HWL = 9.20 m, LWL = 0.50 m
	Type	Raw Water Pumping	
	Intake Pump	(1st Stage) 36.7	m³/min x 17 m x 3 units (+1 standby)
Treatment Process			
	1. Rapid Mixing		
	2. Flocculation		
	3. Sedimentation		
	4 Filtration		
	5 Disinfection		
Receiving Well			
	Type	Recutangular	
	Retention Time	9.0 sec	
	Size & Q'ty	1.4 mW x	11.2 mL x 1.15 mD x 1 unit
Rapid Mixing			
	Type	Vertical Mixer	
	Retention Time	1.4 min	
	Size & Q'ty	2.5 mW x	2.5 mL x 5.04 mD x 4 units
	Equipment	None	
Flocculation			
	Type	Vertical Mixer	
	Retention Time	21 min	
	Size & Q'ty	6.1 mW x	6.1 mW x 4.29 mD x 12 units
	Equipment	None	
Sedimentation Tank			
	Type	Up-Flow with Lamella Plate (Tube Settler)	
	Retention Time	58.2 min,	1.0 hr
	Size & Q'ty	16.5 mL x	6.1 mW x 4.34 mD x 12 units
	Surface Load	74.5 mm/min	
	Trough/Pipe	Lamella Plate, Orifice Trough	
	Sludge Removal	Sludge Extraction Valve (Pneumatic)	
	Equipment	Sludge Extraction Valve	
	Operation	Sludge Removal - Auto	
Filter			
	Type	Gravity, Single Media, Constant Flow, Level Control	
	Filtration rate	168 m/d (	7.00 m/hr) 183 m/hr at washing
	Filter Bed Area	64.4 m²	
	Size & Q'ty	2.45 mW x	2 beds x 13.14 mL x 12 filters
	Filter Media	Sand : 1.0 mm x 1000 mm	
	Washing Rate	Air Scour : 0.116/0.88	m/min Wash : 0.168 m/min Rincing : 0.334 m/min
	Washing System	Backwashing (1.0 min), Air Scouring + Backwashing (5 + 25 min), Rincing (8 min)	
	Wash Trough	7 trough/bed x 2 beds/filter	
	Equipment	Inlet Gate, Outlet Valve, Level Control Siphon, Siphon Regulation System	
		Washwater Inlet Valve,Washwater Discharge Gate, Washwater Pump	
		Scour Air Inlet Valve, Air Blower	
	Operation	Automatic & Step-by-step	

Chemicals	
Alum	Tank + Mixer : 3 , Dosing Pump : 3
Lime	Tank + Mixer : 3, Lime Pump : 3
Chlorine	Chlorinator -Pre : 3(1), -Post : 3(1)
Clear Water Reservoir	HWL = 12.8 m, LWL = 8.37 m
Reservoir	11,600 m^3 x 2 reservoirs
Clear Water Pump	HWL = 13.2 m, LWL = 8.5 m
Distribution	(1 to 6) 30.0 m^3/min x 53 m x 6 units
Sludge Treatment Facility	Nirouth - 1nd Stage + 2nd Stage + 3rd Stage
WTP Capacity	390,000 m^3/d
Raw water	Turbidity 210 NTU (asumption for 3 months average in rainy season)
Sludge Treatment Capacity	76.92 ds-ton/d
Treatment Process	
1. Backwash Wastewater Tank 2. Sludge Thickener 3. Dewatering Machine	
Backwash Wastewater Tank	
Type	Recutangular
Retention Time	2.0 hrs x 4 tanks
Size & Q'ty	10 mW x 25 mL x 3.5 mD x 4 units
Sludge Thickener	
Type	Circular
Retention Time	12.0 hrs
Size & Q'ty	13.0 m dia. x 4.0 mD x 2 units
Sludge Dewatering Machine	
Type	Centrifuge
Retention Time	2000 kg-ds/hr x 3 units (includeing 1 unit for standby)
Size	20 mW x 30 mL

Source: JICA Data Collection Survey Team

a.3 Koh Norea WTP Phase III

Name of Water Treatment Plant : Koh Norea

Capacity		150,000 m^3/d
Water Source		157,500 m^3/d Mekong River HHWL = 10.20 m, LLWL = 0.10 m
Treatment Process		50,000 m^3/d x 3 trains
1. Rapid Mixing 2. Flocculation 3. Sedimentation 4 Filtration 5 Disinfection		
Receiving Well		
	Type	Recutangular
	Retention Time	30.6 sec
	Size & Q'ty	1.4 mW x 11 mL x 1.15 mD x 1 unit x 3 trains
Rapid Mixing		
	Type	Vertical Mixer
	Retention Time	1.7 min
	Size & Q'ty	2.4 mW x 2.4 mL x 3.46 mD x 3 units x 3 trains
	Equipment	None
Flocculation		
	Type	Vertical Mixer
	Retention Time	23.2 min
	Size & Q'ty	7.09 mW x 5.5 mL x 5.17 mD x 4 units x 3 trains
	Equipment	None
Sedimentation Tank		
	Type	Inclined Plate + Up-Flow
	Retention Time	1.1 hr
	Size & Q'ty	7.09 mW x 15.2 mL x 5.16 mD x 4 units x 3 trains
	Surface Load	241.6 mm/min
	Trough/Pipe	Orifice Trough
	Sludge Removal	Sludge Wihtdrawal Valve
	Equipment	Inclined Plate, Orifice Trough, Sludge Wihtdrawal Valve
	Operation	Sludge Removal-Mamual
Filter		Horizontal Cylindrical Pressured Filter
	Type	Open, Dual Media, Costant Rate, Costant Level
	Filtration rate	149 m/d (6.2108 m/hr) 186 m/hr at washing
	Filter Bed Area	67.09 m^2 x 5 filters x 3 trains
	Size & Q'ty	4.57 m Dia. x 14.7 mL x 5 filters x 3 trains
	Filter Media	Sand : 1.0 mm x 1000 mm
	Washing System	Air Scouring (5-8 min) + Backwashing (10-15 min)
	Washing Rate	Air Scour : 0.205 m/min Backwash : 0.056 m/min
	Trough	Both side of filter
	Equipment	Inlet Gate, Outlet Valve, Outlet Level Control Syphon, Backwash Valve, Drain Valve
		Backwash Pump, Air Scouring Valve, Air Blower
	Operation	Auto/Manual

Chemicals		
	PAC	Tank + Mixer : 2 , Dosing Pump : 2 (1)
	Lime	Tank + Mixer : 2, Dosing Pump : 2 (1)
	Chlorine	Electrolyser - Pre : 1, - Post : 1, Dosing Pump - Pre : 2 (1), - Post : 2 (1)
Sludge Treatment Facility		
WTP Capacity		150,000 m^3/d
	Raw water	Turbidity 210 NTU (asumption for 3 months average in rainy season)
Sludge Treatment Capacity		29.59 ds-ton/d
Treatment Process		
1. Backwash Wastewater Tank 2. Sludge Thickener 3. Dewatering Machine		
Backwash Wastewater Tank		
	Type	Recutangular
	Retention Time	2.0 hrs x 2 tanks
	Size & Q'ty	5 mW x 12 mL x 3.5 mD x 2 units
Sludge Thickener		
	Type	Circular
	Retention Time	12.0 hrs
	Size & Q'ty	8.0 m dia. x 4.0 mD x 2 units
Sludge Dewatering Machine		
	Type	Centrifuge
	Retention Time	1500 kg-ds/hr 2 units (includeing 1 unit for standby)
	Size	15 mW x 30 mL

Source: JICA Data Collection Survey Team

a.4 Ta Mouk WTP Phase III

Name of Water Treatment Plant : Ta Mouk I & II

Capacity	200,000 m^3/d x	2 Stages			
Water Source	420,000 m^3/d	Tonle Sap	HWL = 10.9 m, LWL = 1.5m		
Name of Water Treatment Plant :	Ta Mouk I & II				
Capacity	200,000 m^3/d x	2 Stages			
Treatment Process					
1. Rapid Mixing					
2. Flocculation					
3. Sedimentation					
4 Filtration					
5 Disinfection					
Treatment Facility	The following facility is for 200,000m^3/d for each stage.				
Receiving Well					
Type	Recutangular				
Retention Time	18.0 sec				
Size & Q'ty	1.4 mW x	11.2 mL x	1.15 mD x	2 unit	
Rapid Mixing					
Type	Vertical Mixer				
Retention Time	0.9 min				
Size & Q'ty	2.5 mW x	2.5 mL x	5.04 mD x	4 units	
Equipment	None				
Flocculation					
Type	Vertical Mixer				
Retention Time	18 min				
Size & Q'ty	6.1 mW x	6.1 mW x	4.29 mD x	16 units	
Equipment	None				
Sedimentation Tank					
Type	Up-Flow with Lamella Plate (Tube Settler)				
Retention Time	50.3 min,	0.8 hr			
Size & Q'ty	16.5 mL x	6.1 mW x	4.34 mD x	16 units	
Surface Load	86.3 mm/min				
Trough/Pipe	Tube Settler, Orifice Trough				
Sludge Removal	Sludge Extraction Valve (Pneumatic)				
Equipment	Sludge Extraction Valve				
Operation	Sludge Removal - Auto				
Filter					
Type	Gravity, Single Media, Constant Flow, Level Control				
Filtration rate	259 m/d (	10.79 m/hr)	283 m/hr at washing		
Filter Bed Area	64.4 m^2				
Size & Q'ty	2.45 mW x	2 beds x	13.14 mL x	12 filters	
Filter Media	Sand : 1.0 mm x 1000 mm				
Washing Rate	Air Scour : 0.116/0.88 m/min	Wash :	0.168 m/min	Rincing :	0.334 m/min
Washing System	Backwashing (1.0 min), Air Scouring + Backwashing (5 + 25 min), Rincing (8 min)				
Wash Trough	7 trough/bed x 2 beds/filter				
Equipment	Inlet Gate, Outlet Valve, Level Control Siphon, Siphon Regulation System				
	Washwater Inlet Valve,Washwater Discharge Gate, Washwater Pump				
	Scour Air Inlet Valve, Air Blower				
Operation	Automatic & Step-by-step				

Chemicals	
Alum	Tank + Mixer : 3 , Dosing Pump : 3
Lime	Tank + Mixer : 3, Lime Pump : 3
Chlorine	Chlorinator -Pre : 3(1), -Post : 3(1)
Clear Water Reservoir	HWL = 12.8 m, LWL = 8.37 m
Reservoir	11,600 m^3 x 2 reservoirs
Clear Water Pump	HWL = 13.2 m, LWL = 8.5 m
Distribution	(1 to 6) 30.0 m^3/min x 53 m x 6 units
Sludge Treatment Facility	Ta Mouk - 1st Stage + 2nd Stage + 3rd Stage
WTP Capacity	400,000 m^3/d
Raw water	Turbidity 210 NTU (asumption for 3 months average in rainy season)
Sludge Treatment Capacity	78.89 ds-ton/d
Treatment Process	
1. Backwash Wastewater Tank 2. Sludge Thickener 3. Dewatering Machine	
Backwash Wastewater Tank	
Type	Recutangular
Retention Time	2.0 hrs x 2 tanks
Size & Q'ty	9 mW x 20 mL x 3.5 mD x 2 units
Sludge Thickener	
Type	Circular
Retention Time	12.0 hrs
Size & Q'ty	13.0 m dia. x 4.0 mD x 2 units
Sludge Dewatering Machine	
Type	Centrifuge
Retention Time	2000 kg-ds/hr x 3 units (includeing 1 unit for standby)
Size	20 mW x 30 mL

Source: JICA Data Collection Survey Team

a.5 Khsach Kandal WTP Phase III

Name of Water Treatment Plant : Khsach Kandal

Capacity		100,000 m³/d
Water Source		105,000 m³/d Mekong River HHWL = 10.20 m, LLWL = 0.10 m
Treatment Process		50,000 m³/d x 2 trains
1. Rapid Mixing 2. Flocculation 3. Sedimentation 4 Filtration 5 Disinfection		
Receiving Well		
	Type	Recutangular
	Retention Time	30.6 sec
	Size & Q'ty	1.4 mW x 11 mL x 1.15 mD x 1 unit x2 trains
Rapid Mixing		
	Type	Vertical Mixer
	Retention Time	2.6 min
	Size & Q'ty	2.4 mW x 2.4 mL x 3.46 mD x 3 unit x2 trains
	Equipment	None
Flocculation		
	Type	Vertical Mixer
	Retention Time	34.8 min
	Size & Q'ty	7.09 mW x 5.5 mL x 5.17 mD x 4 unit x2 trains
	Equipment	None
Sedimentation Tank		
	Type	Inclined Plate + Up-Flow
	Retention Time	1.6 hr
	Size & Q'ty	7.09 mW x 15.2 mL x 5.16 mD x 4 unit x2 trains
	Surface Load	161.1 mm/min
	Trough/Pipe	Orifice Trough
	Sludge Removal	Sludge Wihtdrawal Valve
	Equipment	Inclined Plate, Orifice Trough, Sludge Wihtdrawal Valve
	Operation	Sludge Removal-Mamual
Filter		Horizontal Cylindrical Pressured Filter
	Type	Open, Dual Media, Costant Rate, Costant Level
	Filtration rate	149 m/d (6.2108 m/hr) 186 m/hr at washing
	Filter Bed Area	67.09 m² x 5 filters x 2 trains
	Size & Q'ty	4.57 m Dia. x 14.7 mL x 5 unit x 2 trains
	Filter Media	Sand : 1.0 mm x 1000 mm
	Washing System	Air Scouring (5-8 min) + Backwashing (10-15 min)
	Washing Rate	Air Scour : 1.00 m/min Backwash : 0.3 m/min
	Trough	Both side of filter
	Equipment	Inlet Gate, Outlet Valve, Outlet Level Control Syphon, Backwash Valve, Drain Valve Backwash Pump, Air Scouring Valve, Air Blower
	Operation	Auto/Manual

Chemicals	
PAC	Tank + Mixer : 2 , Dosing Pump : 2 (1)
Lime	Tank + Mixer : 2, Dosing Pump : 2 (1)
Chlorine	Electrolyser - Pre : 1, - Post : 1, Dosing Pump - Pre : 2 (1), - Post : 2 (1)
Sludge Treatment Facility	
WTP Capacity	100,000 m^3/d
Raw water	Turbidity 210 NTU (asumption for 3 months average in rainy season)
Sludge Treatment Capacity	19.72 ds-ton/d
Treatment Process	
1. Backwash Wastewater Tank 2. Sludge Thickener 3. Dewatering Machine	
Backwash Wastewater Tank	
Type	Recutangular
Retention Time	2.0 hrs x 2 tanks
Size & Q'ty	8 mW x 18 mL x 3.5 mD x 2 units
Sludge Thickener	
Type	Circular
Retention Time	12.0 hrs
Size & Q'ty	7.0 m dia. x 4.0 mD x 2 units
Sludge Dewatering Machine	
Type	Centrifuge
Retention Time	1000 kg-ds/hr 2 units (includeing 1 unit for standby)
Size	15 mW x 30 mL

Source: JICA Data Collection Survey Team

a.6 New Airport City WTP Phase III

Name of Water Treatment Plant : New Airport

Capacity	30,000 m^3/d
Water Source	33,000 m^3/d Mekong River HWL = 10.9 m, LWL = 1.5m
Treatment Process	
1. Rapid Mixing 2. Flocculation 3. Sedimentation 4 Filtration 5 Disinfection	
Receiving Well	
Type	Recutangular
Retention Time	26.8 sec
Size & Q'ty	2.25 mW x 1.2 mL x 1.15 mD x 3 units
Rapid Mixing	
Type	Vertical Mixer
Retention Time	2.1 min
Size & Q'ty	2.25 mW x 1.9 mL x 3.46 mD x 3 units
Equipment	None
Flocculation	
Type	Vertical Mixer
Retention Time	23.4 min
Size & Q'ty	3.5 mW x 6.1 mL x 3.8 mD x 6 units
Equipment	None
Sedimentation Tank	
Type	Inclined Plate + Up-Flow
Retention Time	3.3 hr
Size & Q'ty	3.5 mW x 12.5 mL x 5.16 mD x 6 units
Surface Load	79.4 mm/min
Trough/Pipe	Orifice Trough
Sludge Removal	Sludge Wihtdrawal Valve
Equipment	Inclined Plate, Orifice Trough, Sludge Wihtdrawal Valve
Operation	Sludge Removal-Mamual
Filter	Horizontal Cylindrical Pressured Filter
Type	Open, Dual Media, Costant Rate, Costant Level
Filtration rate	167 m/d (6.9444 m/hr) 200 m/hr at washing
Filter Bed Area	30.00 m^2 x 6 filters
Size & Q'ty	3 mW x 10.0 mL x 6 filters
Filter Media	Sand : 1.0 mm x 1000 mm
Washing System	Air Scouring (5-8 min) + Backwashing (10-15 min)
Washing Rate	Air Scour : 1.200 m/min Wash : 0.3 m/min Rincing : 0.867 m/min
Trough	Both side of filter
Equipment	Inlet Gate, Outlet Valve, Outlet Level Control Syphon, Backwash Valve, Drain Valve
	Backwash Pump, Air Scouring Valve, Air Blower
Operation	Auto/Manual
Chemicals	
PAC	Tank + Mixer : 2 , Dosing Pump : 2 (1)
Lime	Tank + Mixer : 2, Dosing Pump : 2 (1)
Chlorine	Electrolyser - Pre : 1, - Post : 1, Dosing Pump - Pre : 2 (1), - Post : 2 (1)
Clear Water Reservoir	
	5,000 m^3 x 2 Reservoirs
Clear Water Pump	
Distribution	11.0 m^3/min x 45 m x 110 kW x 4 units

Sludge Treatment Facility	
WTP Capacity	30,000 m^3/d
Raw water	Turbidity 210 NTU (asumption for 3 months average in rainy season)
Sludge Treatment Capacity	5.92 ds-ton/d
Treatment Process	
1. Backwash Wastewater Tank 2. Sludge Thickener 3. Dewatering Machine	
Backwash Wastewater Tank	
Type	Recutangular
Retention Time	4.0 hrs x 2 tanks
Size & Q'ty	4 mW x 10 mL x 3.5 mD x 2 units
Sludge Thickener	
Type	Circular
Retention Time	12.0 hrs
Size & Q'ty	4.0 m dia. x 4.0 mD x 2 units
Sludge Dewatering	
Type	Centrifuge
Retention Time	300 kg-ds/hr x 2 units (includeing 1 unit for standby)
Size	9 mW x 17 mL

Source: JICA Data Collection Survey Team

(7) General Layout of WTPs

1) Bakheng WTP

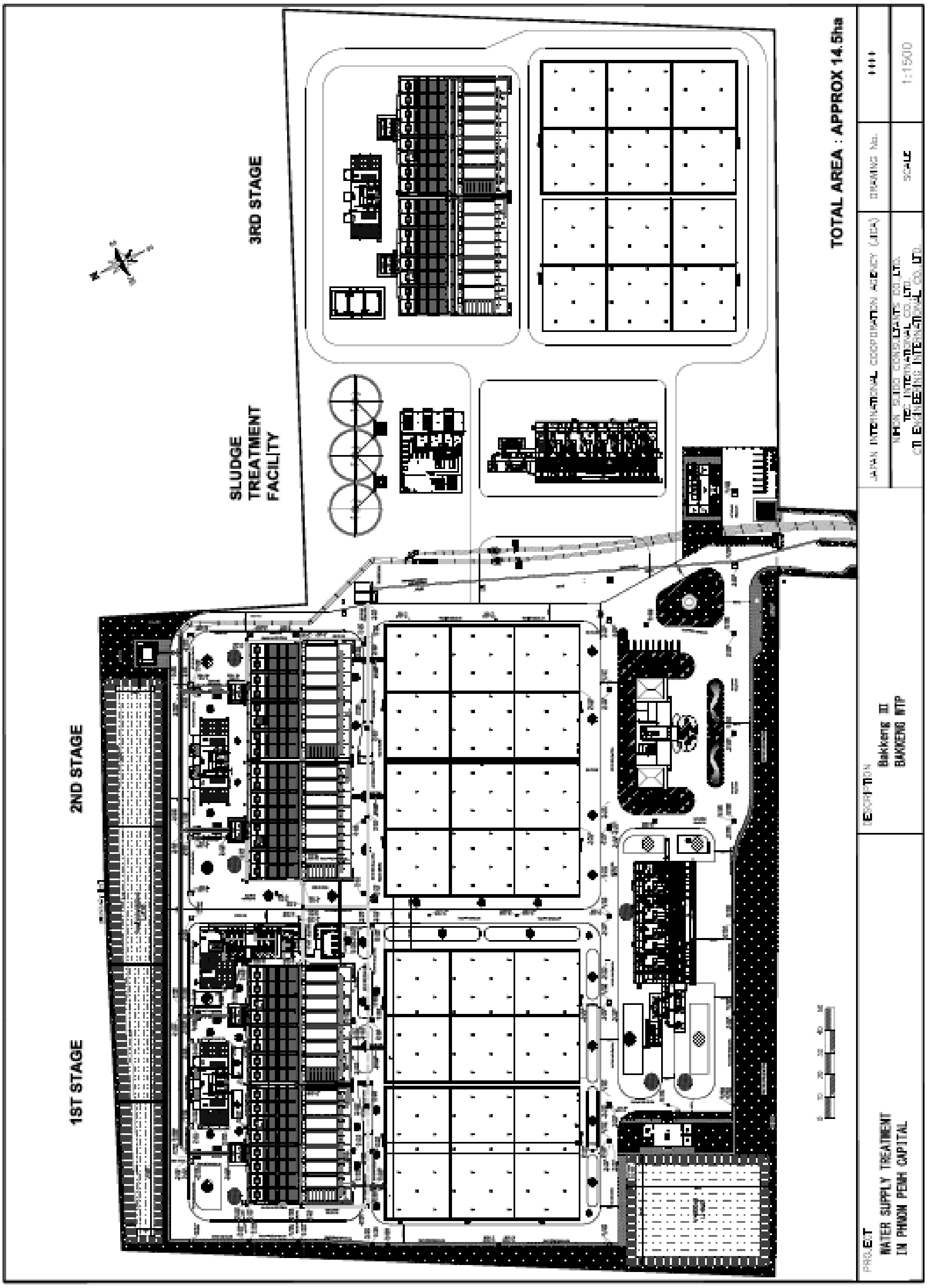


Table 6.1.20 Bakheng WTP - Layout Plan
Source: JICA Data Collection Survey Team

2) Nirodh WTP

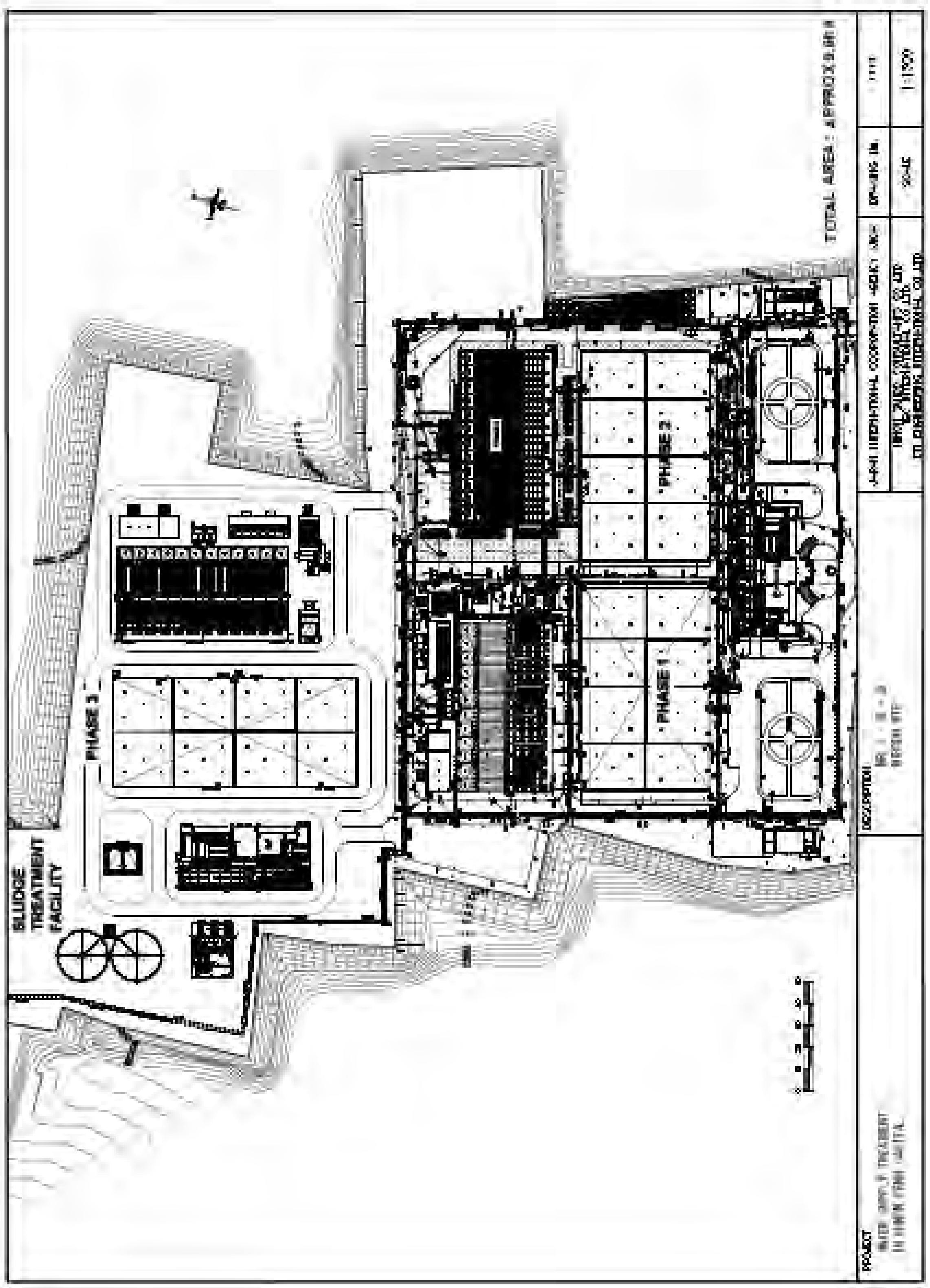


Table 6.1.20 Nirodh WTP - Layout Plan
Source: JICA Data Collection Survey Team

3) Koh Norea WTP

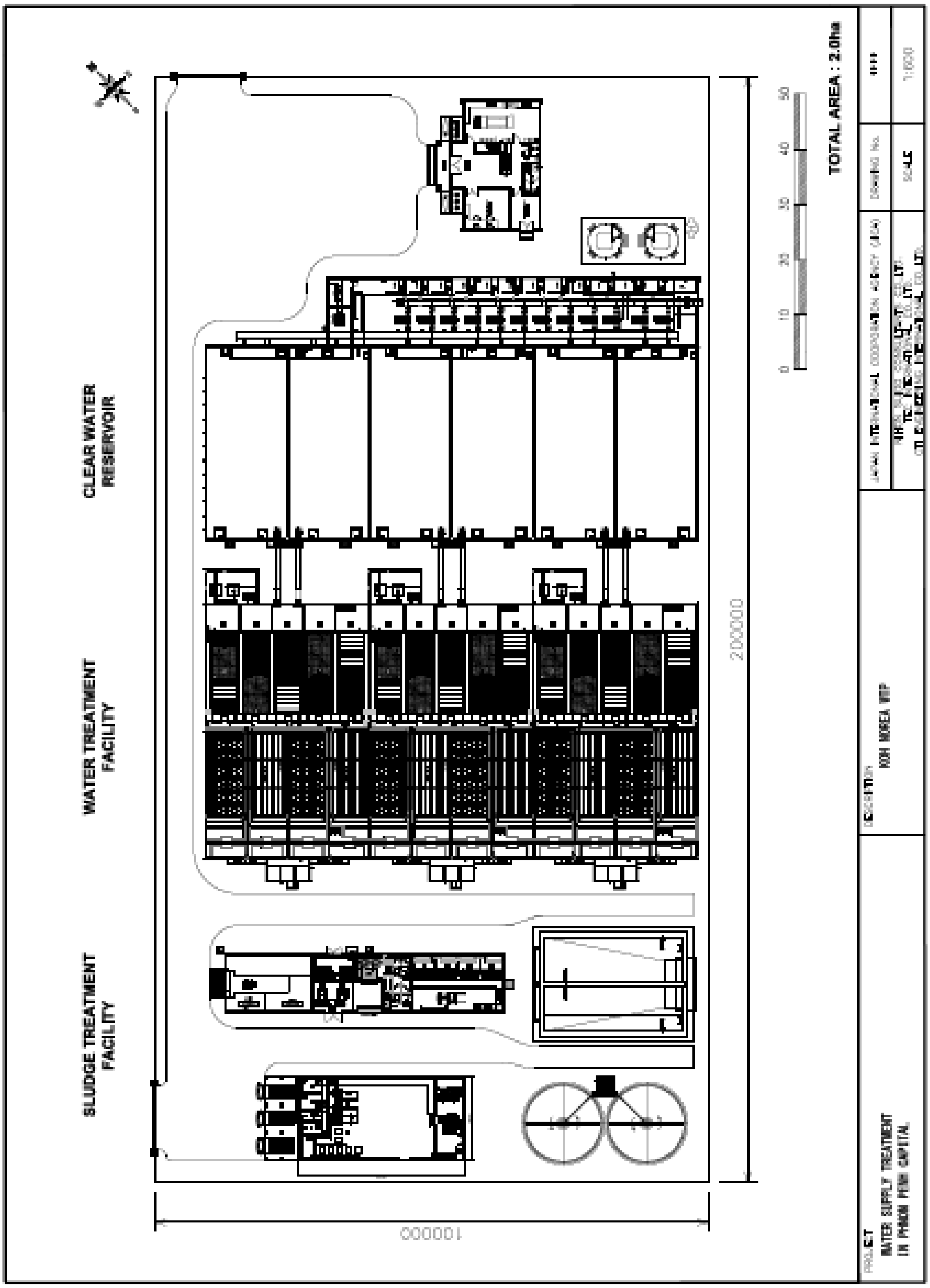


Table 6.1.20 Koh Norea WTP - Layout Plan
Source: JICA Data Collection Survey Team

4) Ta Mouk WTP

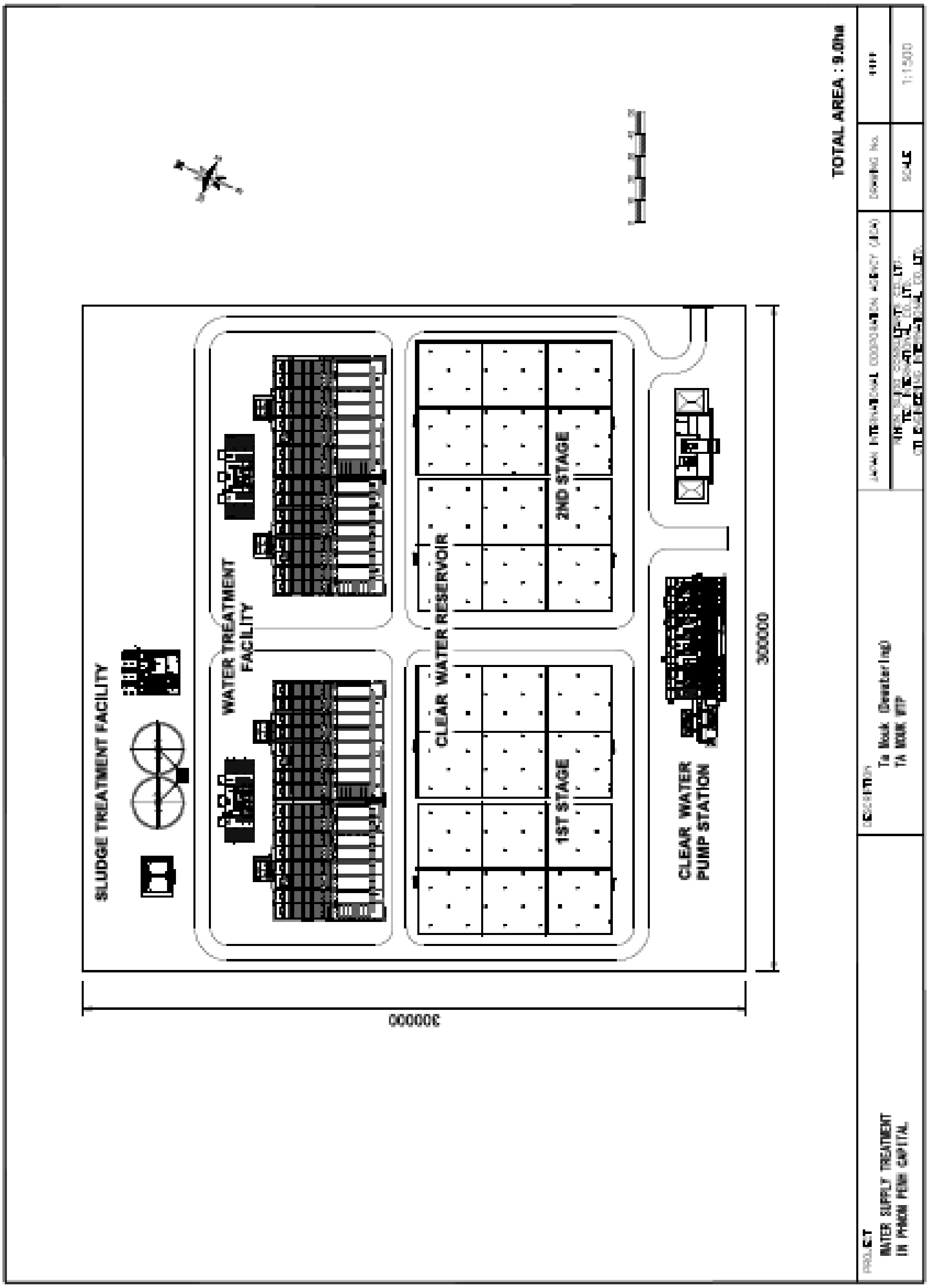


Table 6.1.20 Ta Mouk WTP - Layout Plan

Source: JICA Data Collection Survey Team

5) Khsach Kanda WTP

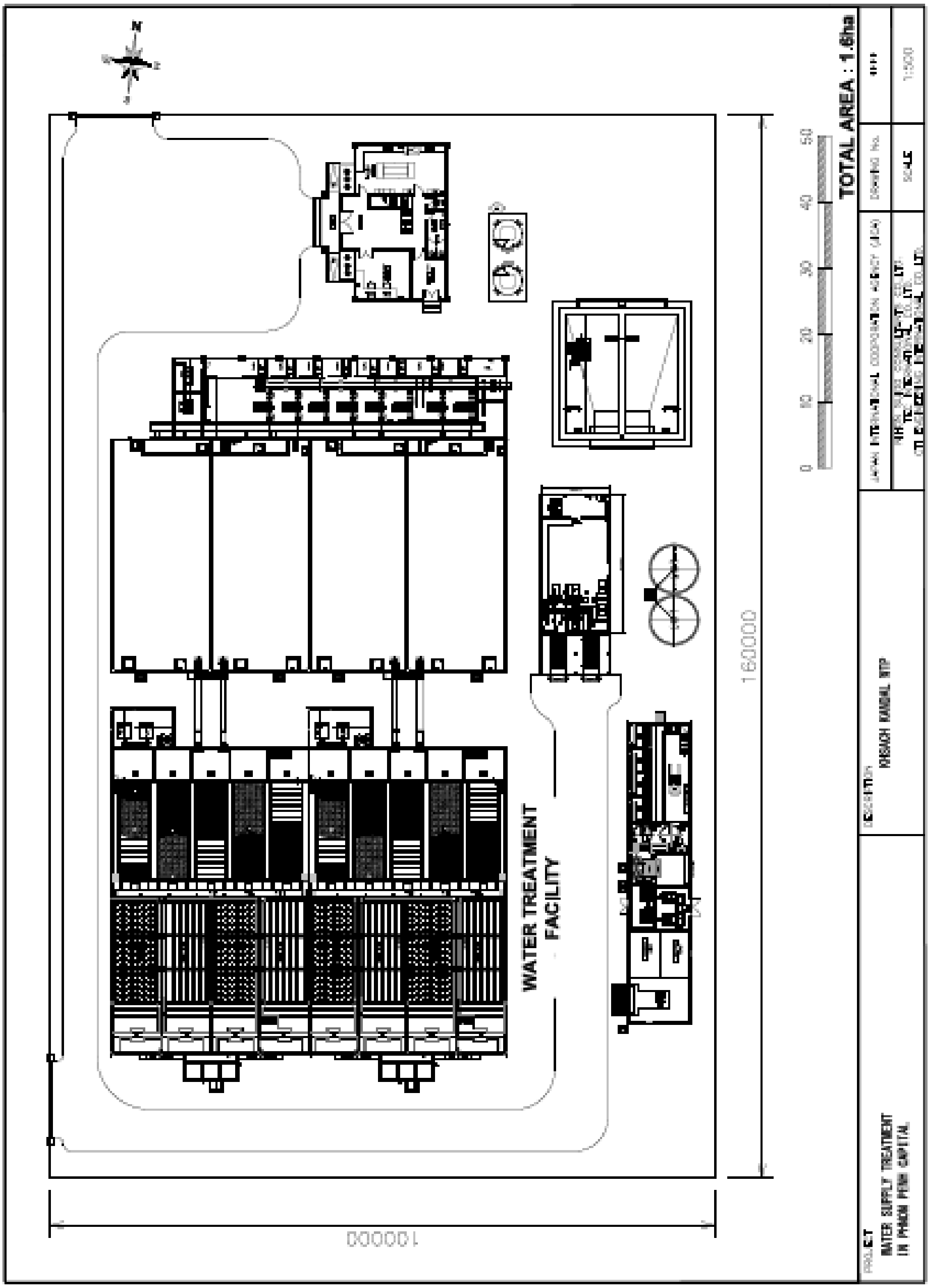


Table 6.1.20 Khsach Kanda WTP - Layout Plan
Source: JICA Data Collection Survey Team

6) New Airport City WTP

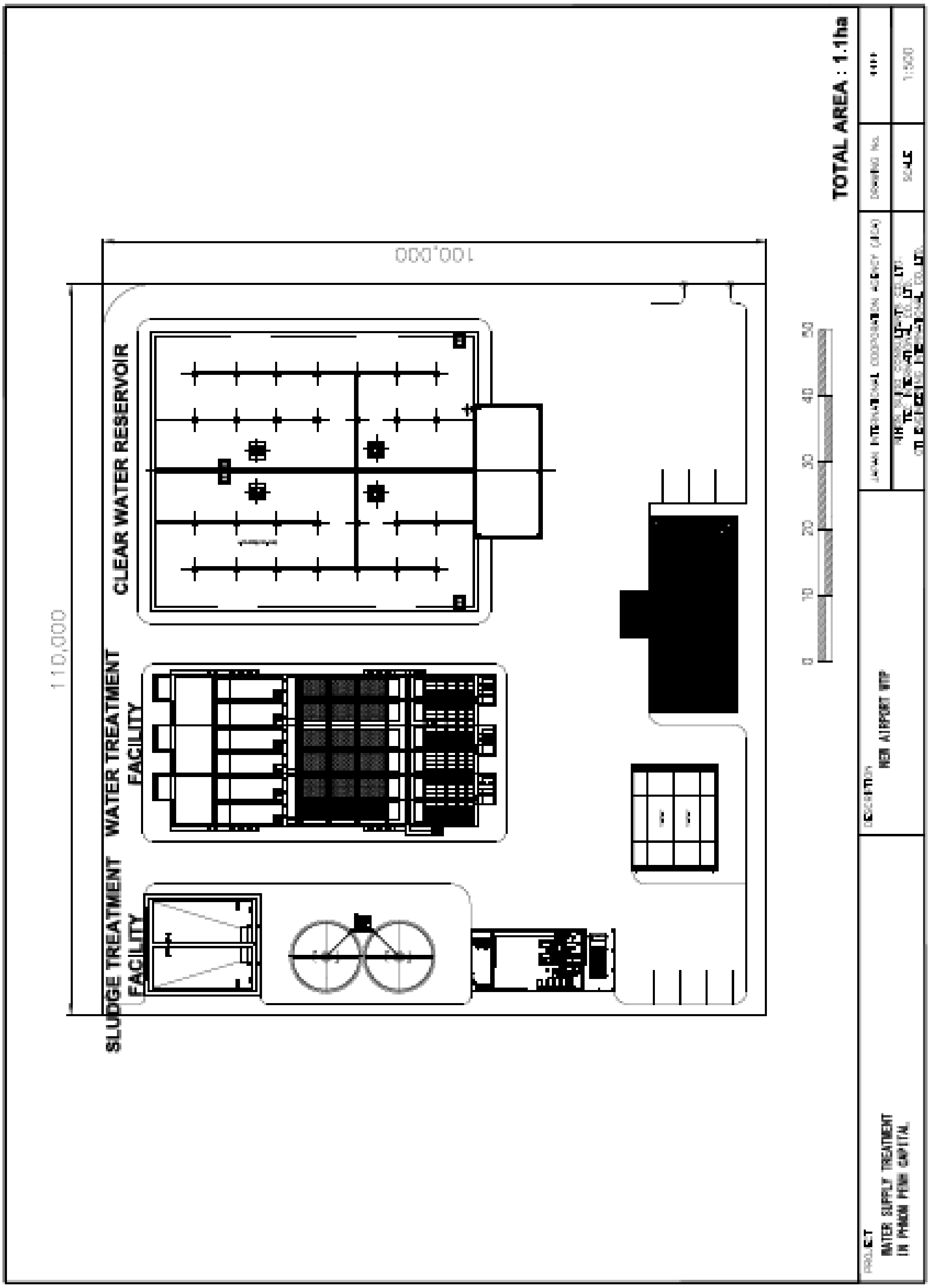


Table 6.1.20 New Airport City WTP - Layout Plan
Source: JICA Data Collection Survey Team

(8) Proposed Re-Construction Plan of Phum Prek Phase I Facilities and Future Development of Sludge Treatment Facilities for Entire Phum Prek WTP

1) Re-Construction Method

The Stage 1 sedimentation basin and filter (built in 1965) and the No.1 distribution basin (built in 1959) have been in operation for about 60 years, so it is time to rebuild them. A reconstruction method that minimizes the decline in treated water volume will be considered. At this point, the water intake has already been rebuilt, and the water conduit built in 2002 and the rapid agitation pond built in 2005 will be used as they are.

Table 6.2.20 Reconstruction Procedure

Step	Construction phase	Contents	Treated water volume m^3/day	Clean water reservoir Capacity m^3
-1	Present condition	《Facility condition》・・・・・・ Stage1 Sedimentation / Filter:100,000 m^3/day (Constructed in1965) Stage2 Sedimentation / Filter：50,000 m^3/day (Constructed in 2005) No.1 Clear water Reservoir：10,000 m^3 (Constructed in1959) No.2 Clear water Reservoir：10,000 m^3 (Constructed in 1995) No.3 Clear water Reservoir： 5,000 m^3 (Constructed in 2003)	150,000	25,000
0	Expansion completion	Stage3 Sedimentation basin /filter：45,000 m^3/d expansion No.4 Clear water reservoir： 6,000 m^3 expansion 《Facility condition》・・・・・・・・・・・・・・・ Stage1 Sedimentation / Filter：100,000 m^3/day (Constructed in 1965) Stage2 Sedimentation / Filter：50,000 m^3/day (Constructed in 2005) Stage3 Sedimentation / Filter：45,000 m^3/day No.1 Clear water Reservoir：10,000 m^3 (Constructed in1959) No.2 Clear water Reservoir：10,000 m^3 (Constructed in 1995) No.3 Clear water Reservoir： 5,000 m^3 (Constructed in 2003) No.4 Clear water reservoir： 6,000m^3	195,000	31,000
1	Demolish 1	Stage1 Demolish the half of No.1 sedimentation basins / Filters 100,000→50,000 m^3/day （No.1-No.3 sedimentation basin / No.1-No.6 filter） 《Facility condition》・・・・・・・・・・ Stage1sedimentation basins/filters：50,000m^3/day (50,000←100,000 m^3/day) Stage2 sedimentation basin/filter: 50,000 m^3/day (Constructed in 2005) Stage3 sedimentation basin/filter：45,000 m^3/day No.1Clear water reservoir：10,000 m^3 (Constructed in1959) No.2 Clear water reservoir：10,000 m^3 (Constructed in1995) No.3Clear water reservoir： 5,000 m^3 (Constructed in 2003) No.4 Clean water reservoir： 6,000m^3	145,000	31,000
2	Construction	Stage 4 Sedimentation basin/Filter：100,000 m^3/day Stage1Stop the half of sedimentation basin/ filter :50,000→0 m^3/d 《condition of facility》・・・・・・・・・・・・・・・・・・ Stage1Sedimentation basin /Filter： 0 m^3/day (0←50,000 m^3/day) Stage2 Sedimentation basin /Filter：50,000 m^3/day (Constructed in 2005)	195,000	31,000

Step	Construction phase	Contents	Treated water volume m^3/day	Clean water reservoir Capacity m^3
		Stage3 Sedimentation basin /Filter：45,000 m^3/day Stage4 Construct Sedimentation basin /Filter : 100,000 m^3/day No.1 Clear water reservoir：10,000 m^3 (Constructed in 1959) No.2 Clear water reservoir：10,000 m^3 (Constructed in 1995) No.3 Clear water reservoir： 5,000 m^3 (Constructed in 2003) No.4 Clear water reservoir： 6,000 m^3		
3	Demolish 2	Stage1 Demolish the remaining half of Sedimentation basin/Filtration basin (No.4-No.6 Sedimentation basin / No.7-No.12Filters) 《Condition of facility》・・・・・・・・・・・・・・ Stage1Sedimentation basin /Filter： 0 m^3/day Stage2 Sedimentation basin /Filter：50,000 m^3/day (Constructed in 2005) Stage3 Sedimentation basin /Filter：45,000 m^3/day Stage4 Construct new sedimentation basin /Filter： 100,000 m^3/day No.1 Clear water reservoir：10,000 m^3 (Constructed in 1959) No.2 Clear water reservoir：10,000 m^3 (Constructed in 1995) No.3 Clear water reservoir： 5,000 m^3 (Constructed in 2003) No.4 Clear water reservoir： 6,000 m^3	195,000	31,000
4	Construct clear water reservoir	Construct a new10,000m3 clear water reservoir at the place of demolition No.5 Clear water reservoir： 10,000 m^3 《condition of facility》・・・・・・・・・・・・・・ Stage2 Sedimentation basin /Filter：50,000 m^3/day (Constructed in 2005) ~~Stage1Sedimentation basin /Filter： 0 m3/day~~ Stage3 Sedimentation basin /Filter：45,000 m^3/day Stage4 Construct new sedimentation basin /Filter： 100,000 m^3/day No.1 Clear water reservoir：10,000 m^3(Constructed in 1959) No.2 Clear water reservoir：10,000 m^3(Constructed in 1995) No.3 Clear water reservoir： 5,000 m^3(Constructed in 2003) No.4 Clear water reservoir： 6,000 m^3 No.5 Clear water reservoir：10,000 m^3	195,000	41,000
5	Wastewater treatment facility	Demolition No.1clerar water reservoir (10,000 m^3) and construction wastewater treatment facility 《facility condition》・・・・・・・・・・・・・ ~~Stage1Sedimentation basin /Filter： 0 m3/day~~ Stage2 Sedimentation basin/filter :50,000 m^3/day (Constructed in 2005) Stage3 Sedimentation basin/Filter：45,000 m^3/day Stage4 Sedimentation basin/Filter： construct facility of 100,000 m^3/day ~~No.1 Clear water reservoir：10,000 m³(Constructed in 1959)~~ No.2 Clear water reservoir：10,000 m^3 (Constructed in 1995) No.3 Clear water reservoir： 5,000 m^3 (Constructed in 2003) No.4 Clear water reservoir： 6,000 m^3 No.5 Clear water reservoir：10,000 m^3	195,000	31,000

Source: JICA Data Collection Survey Team

a. Survey, Design and Preparation

Survey and design of the existing facilities and preparation for construction is expected to take 12 months.

b. Survey & design period, Construction preparation period

Survey and design of the existing facilities and preparation for construction is expected to take 12 months.

c. Step1: Demolish 1

After the expansion of No.3 Sedimentation basin and filter (45,000 m^3/day) and No.4 Reservoir (6,000 m^3) are completed, No.1 Sedimentation basin and filter (100,000 m^3/day), which was built in 1965 and has been overaged will be demolished and constructed newly (100,000 m^3/day) and designated as No. 4 Sedimentation basin and filter.

First, Demolish half of the No.1 Sedimentation basin and filter (No.1 to No.3 sedimentation basins and No.1 to No.6 filters). Close the communication valve of the raw water pipe (sediment process water) and build a temporary shutoff wall so that the remaining half of sedimentation basin and filters on the mixing pond side can be used.

The flocculators in the floc flocculation basin and the electric valves in the filter will be demolished after the power transmission is stopped. The switchover of electric power equipment and piping shall be considered in the detailed design. The temporary walls will be used to reinforce the walls between the third and fourth sedimentation basins and the sixth and seventh filtration tanks. At the same time, new shutoff walls will be installed in the channels. This will also be considered in the detailed design. During this construction period, the treated water volume will be temporarily reduced by 100,000 m^3/d to 95,000 m^3/d.

The construction period is expected to be about 4 to 6 months. At this point, the treated water volume will be 145,000 m^3/d.

The total capacity of the distribution reservoirs will remain unchanged at 31,000 m^3.

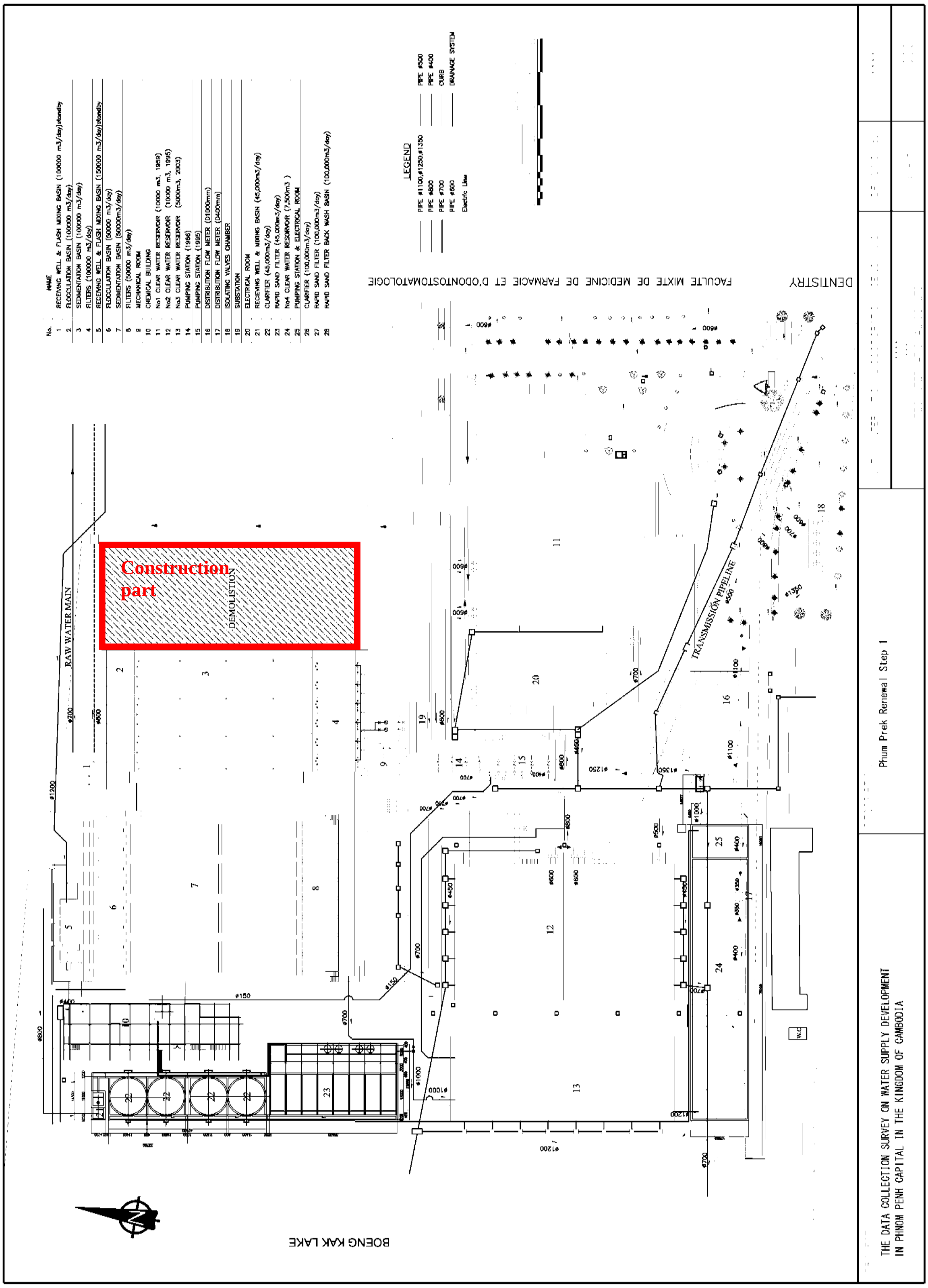


Figure 6.2.23 Re-Construction Plan Step 1
Source: JICA Data Collection Survey Team

d. Step 2: Construction of WTP

To construct the No.4 sedimentation basin and filter (100,000 m^3/day) on 50,000 m^3/day of land, the sedimentation basin is applied to achieve high-rate coagulation and sedimentation without a large footprint. The same idea is applied for the Stage 3 sedimentation basin and filter (45,000 m^3/day). At the final stage of construction, branch pipes from the raw water conduit channel (coagulated water) shall be connected to the No.4 high-rate sedimentations. At the same time, the filtered water pipe will be connected to the existing filtered water basin. The construction period is expected to be about 12 to 18 months.

Upon completion of construction, the treated water amount shall recover from 145,000 m^3/day to 195,000 m^3/day.

PRINCIPLE ON FOUNDATION CONSTRUCTION
Since it can be assumed that the geological conditions are similar to those of the surrounding areas, the No. 4 sedimentation basin and filter will be built on pile foundations. In order to prevent vibrations during construction from affecting the existing structure, the piles will be constructed, for example, by the overall casing method (cutting the ground while rotating and pressing the casing tube into the entire length of the excavation hole, excavating and removing the soil inside the casing tube with a hammer grab, and then constructing the piles with cast-in-place concrete).

PRINCIPLE FOR THE FRAME CONSTRUCTION
When constructing the frame of the No.4 sedimentation basin and filter in Step 2, scaffolding will be used to set up splattering protection sheets to prevent concrete and other materials from being mixed into the pond which will still be in operation.

In addition, since the construction of the structure is to be carried out in a narrow space, it is desirable to make effective use of the yard that has been temporarily widened by dismantling the existing structure in order to facilitate the construction and improve the safety of the work. In this way, the frame on the side of the structure that is left undemolished can be constructed first, and sufficient material age can be secured to mitigate the effects of vibration when the remaining frame is demolished in the next step.

Table 6.2.21 General Summary of the Facilities to Be Re-Constructed

Phum Prek – Reconstruction		
Capacity	100,000 m^3/d	
Treatment Process	1. High-rate Clarifier 2. Filter 3. Clear Water Reservoir	
1. High-rate Clarifier	Type	Up Flow with Tube settler
	Retention Time	Approximately 60 min
	Size	15.6 mL x 15.6 mW x 7 mD
	Q'ty	4 units
	Up-flow Velocity	Approximately 77 mm/min
	Surface Load	Approximately 10 mm/min
	Trough/Pipe	Orifice Trough
	Sludge Removal	5 Desludge Valves (Pneumatic)/unit
	Equipment	Tube settler Collecting Trough
	Operation Desludge- Auto	
2. Filter	Type	Gravity, Single Media, Constant Flow Rate, Natural balancing
	Filtration rate	184 m/d (7.67 m/hr)
	Filter Bed Area	35.7 m^2
	Size & Q'ty	3.5 mW x 10.2 mL x 16 filters
	Filter Media	Silica Sand : (E.S Φ 1.0 mm + U.C<1.7) x 1000 mmD
	Washing Rate	Air Scour :0.9 m/min Backwash: 0.15 m/min & 0.3 m/min.
	Wash Trough	One set
	Equipment	Inlet Valve, Outlet Valve, Backwash valve, Air scouring valve, Waste Valve, Backwash Pump, Air blower
3. Clear Water Reservoir	Effective volume	10,000 m^3
	Size	75.0 mL x 30.0 mW x 5.0 mD

Source: JICA Data Collection Survey Team

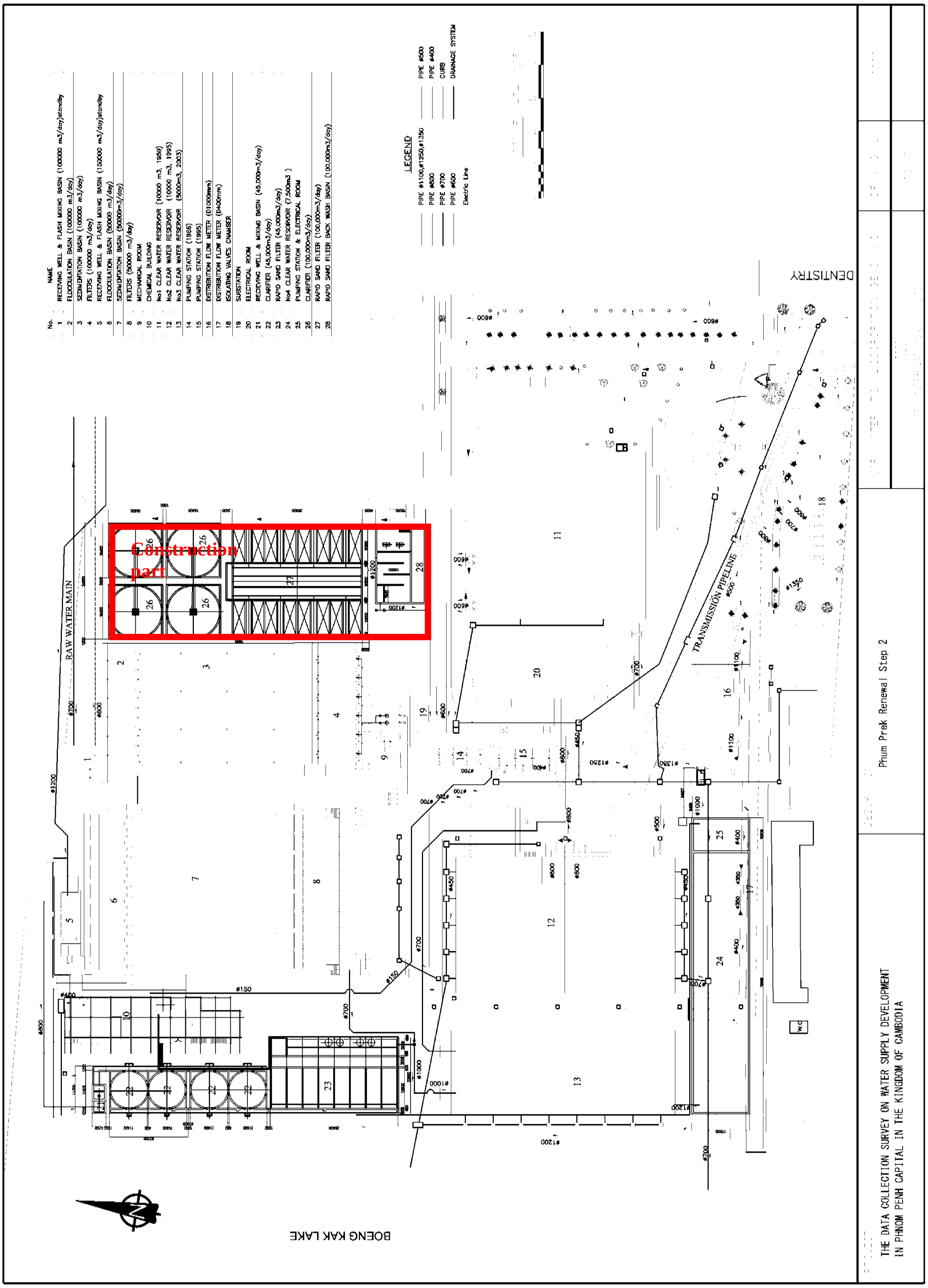


Figure 6.2.24 Re-Construction Plan Step 2

Source: JICA Data Collection Survey Team

e. Step 3: Demolish 2

Demolish the remaining half (sedimentation basins No.4 - No.6 and filters No.7 - No.12) of the No.1 sedimentation basin and filter (100,000 m^3/day). As the existing No.1 sedimentation basin and filter (100,000 m^3/day) shall stop operation when the No.4 sedimentation basin filter (100,000 m^3/day) is completed, the treated water volume shall remain 195,000 m^3/day.

Since the communication valve of the raw water pipe (sedimentation process water) has been closed and it is isolated from the rest of the facilities, the demolish can start continuously. The construction period is estimated to be about 4 to 6 months.

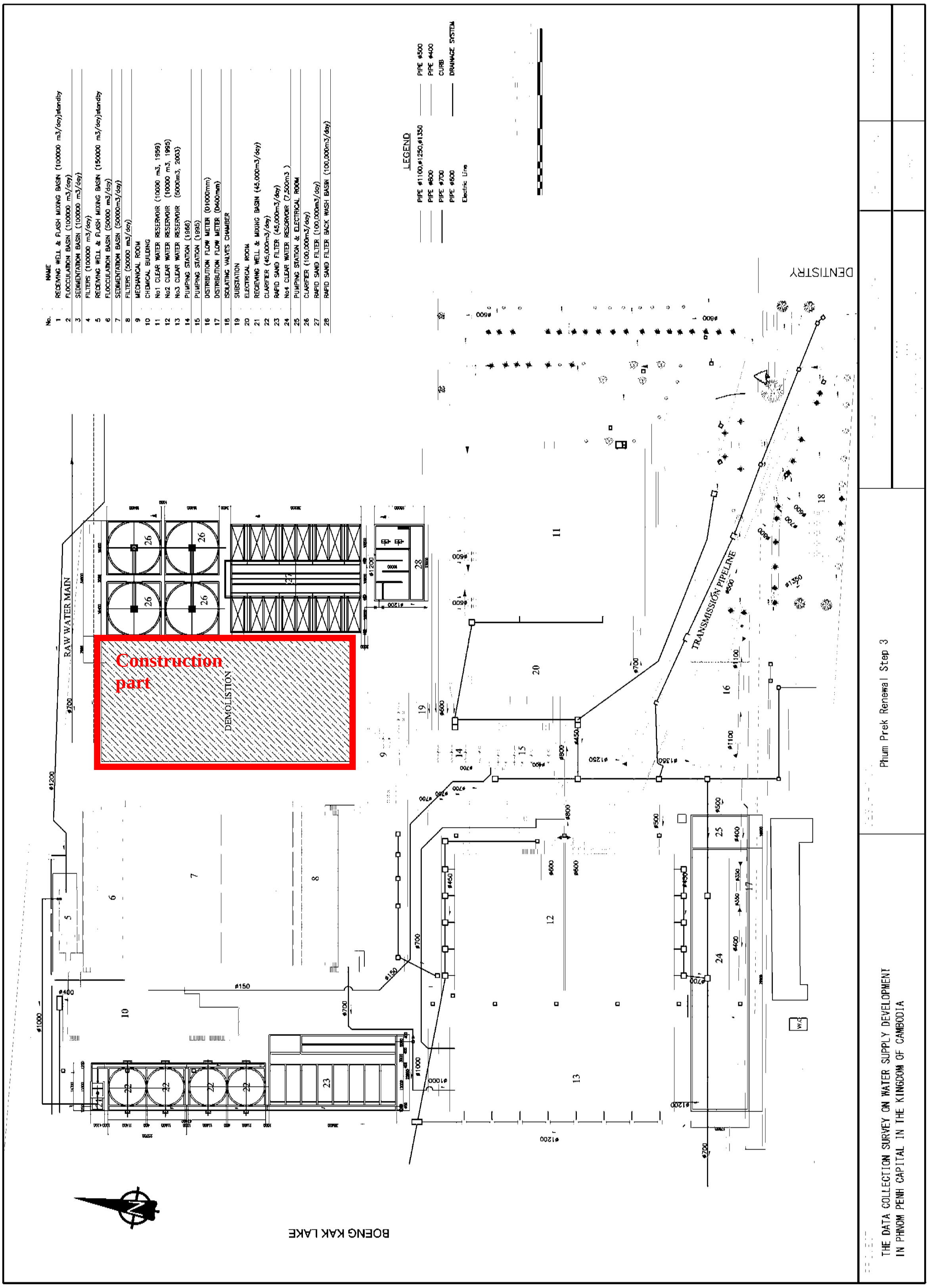


Figure 6.2.25 Re-Construction Plan Step 3
Source: JICA Data Collection Survey Team

f. Step 4: Construction of clear water reservoir

No.4 clear water reservoir (10,000 m^3) shall be constructed where the sedimentation basin and the filter was demolished in Step 3. The clear water reservoir is 41,000 m^3 of total capacity. The construction period is estimated to be approximately 9 to 15 months.

The policy of foundation works and the frame works shall be the same as Step 2.

Table 6.2.22 Foundation Work

Name of Water Treatment Plant :	Phum Prek - New
Clear Water Resorvoir	HWL = 11.1 m, LWL = 6.1m
Effective volume	10,000 m^3
Size	75.0 mL x 30.0 mW x 5.0 mD
Sludge Disposal	Slucge Basin+ Sludge Thickning + Dewatering + Sludge disposal to permitted place

Source: JICA Data Collection Survey Team

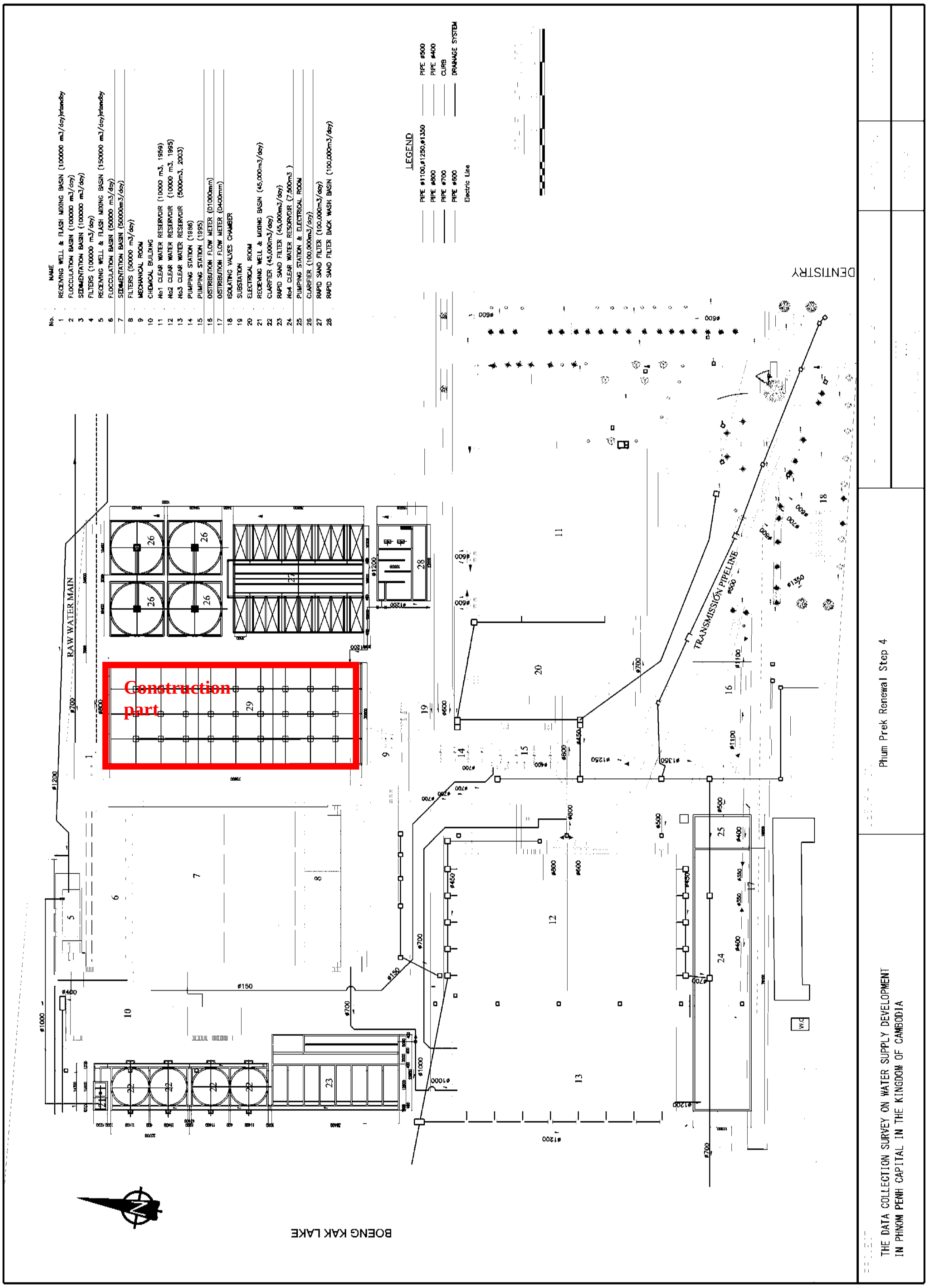


Figure 6.2.26 Re-Construction Plan Step 4
Source: JICA Data Collection Survey Team

g. Step 5: Construction of wastewater treatment facilities

The existing No.1 clear water reservoir (10,000 m^3) shall be demolished. The total capacity of the distribution ponds shall be 31,000 m^3 of total capacity. The construction period is expected to be about 12-18 months.

Table 6.2.23 Facility Requirements

Sludge Treatment Facility											
WTP Capacity			195,000	m^3/d							
		Raw water	Turbidity	210	NTU (assumption for 3 months average in rainy season)						
Sludge Treatment Capacity			38.5	ton-ds/d							
Treatment Process											
	1.	Backwash Wastewater Tank									
	2.	Sludge Thickener									
	3.	Dewatering Machine									
Backwash Wastewater Tank											
		Type	Rectangular								
		Retention Time	2.0	hrs x	2	tanks					
		Size & Q'ty	7.5	mW x	30	mL x	3.5	mD x	2	units	
Sludge Thickener											
		Type	Circular								
		Retention Time	24.0	hrs							
		Size & Q'ty	13.0	m dia. x	4.0	mD x	2	units			
Sludge Dewatering											
		Type	Centrifuge								
		Retention Time	1500	kg-ds/hr	2	units (including 1 unit for standby)					
		Size	15	mW x	30	mL					

Source: JICA Data Collection Survey Team

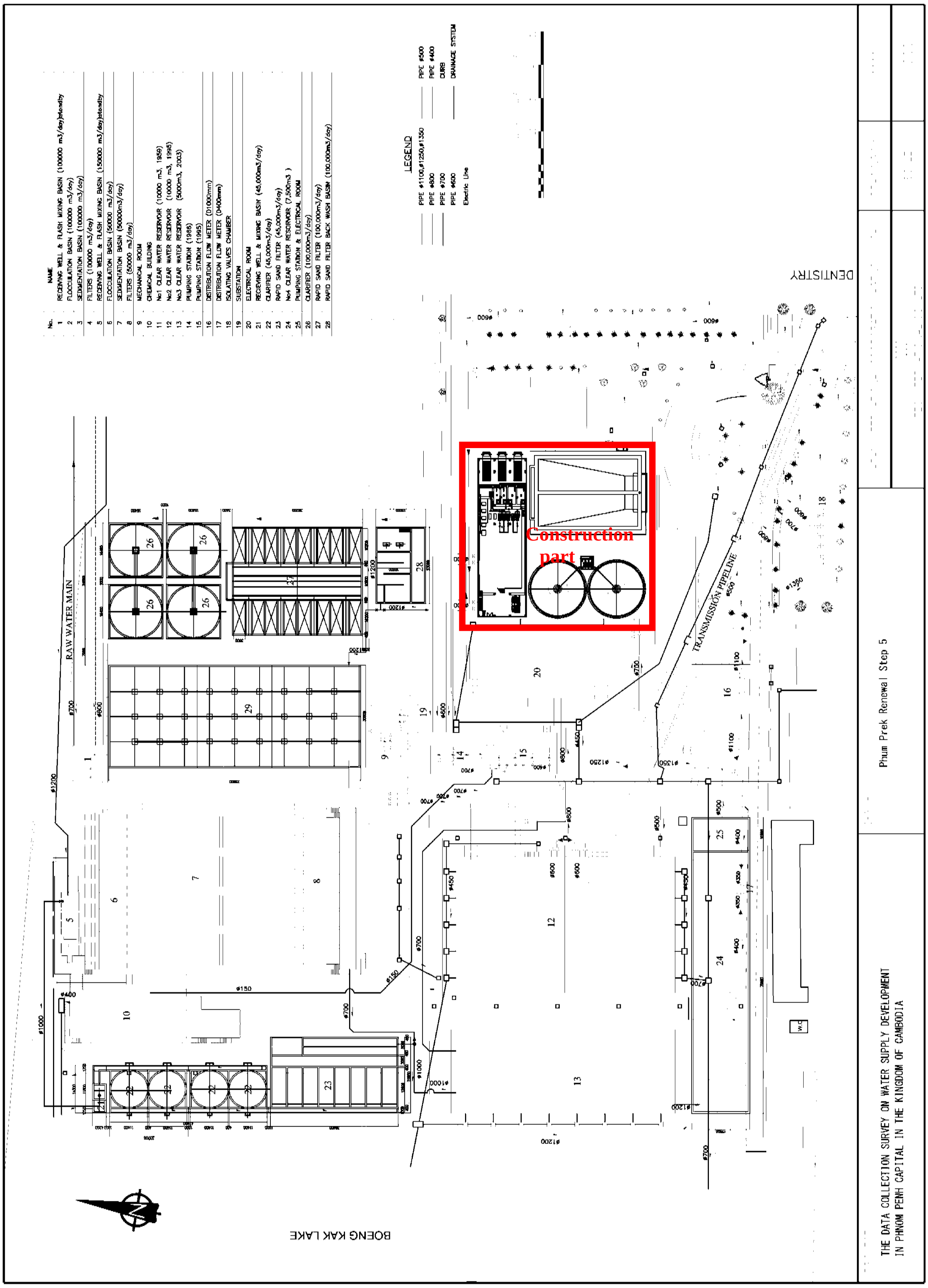


Figure 6.2.27 Re-Construction Plan Step 5
Source: JICA Data Collection Survey Team

2) Organizing the construction process
The outline construction process from Step 1 to Step 5 is expected to be as follows.

The approximate construction period shown here is the compilation of the expected construction periods outlined in (1) to (5) above.

Table 6.2.24 Assumed Construction Schedule

<table>
<tr><td colspan="12">1st year</td><td colspan="12">2nd year</td><td colspan="12">3rd year</td><td colspan="12">4th year</td><td colspan="12">5th year</td><td colspan="12">6th year</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td></td><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>36</td><td>37</td><td>38</td><td>39</td><td>40</td><td>41</td><td>42</td><td>43</td><td>44</td><td>45</td><td>46</td><td>47</td><td>48</td><td>49</td><td>50</td><td>51</td><td>52</td><td>53</td><td>54</td><td>55</td><td>56</td><td>57</td><td>58</td><td>59</td><td>60</td><td>61</td><td>62</td><td>63</td><td>64</td><td>65</td><td>66</td><td>67</td><td>68</td><td>69</td><td>70</td><td>71</td><td>72</td></tr>
<tr><td colspan="12">Survey / design and construction preparation</td><td colspan="5">Step1
Demolish WTP 1</td><td colspan="15">Step2
Construction WTP</td><td colspan="5">Step3
Demolish WTP 2</td><td colspan="12">Step4
Construction Clear Water Resovoir</td><td colspan="15">Step5
Demolish of Clear water reservoir and construction of wastewater treatment facility</td><td colspan="8"></td></tr>
</table>

Source: JICA Data Collection Survey Team

3) Points to keep in mind when rebuilding

a. Reduce down time of existing facilities (During demolition/construction)

In Step 1, 1/2 of the No. 1 sedimentation basin and filter (100,000 m^3/day) will be demolished, and a temporary wall will be constructed so that 50,000 m^3 / day can be operated. It is expected that it will take about 5 months to complete, during which time No. 2 (50,000 m^3/day) and No. 3 (45,000 m^3/day) will be operational for a total capacity of 95,000 m^3/day. When the temporary wall is completed, 50,000 m^3 / day will be restored and the processing capacity will become 145,000 m^3/day (At the end of Step 1).

When the No. 4 sedimentation basin and filter (100,000 m^3/day) is completed in Step 2, the No. 1 sedimentation basin and filter (50,000 m^3/day) will stop. No. 2 (50,000 m^3/day) and No. 3 will remain, resulting in a processing capacity of 195,000 m^3/day.

b. Prevention of impacts to existing structures (damage, collapse, vibration, subsidence, etc.)

Crushing of concrete is assumed to be done by a breaker but crushing will generally not be carried out in-situ (at the location where the existing structure is located, i.e., at the WTP). The concrete will be cut and divided by the flat saw method, wire saw method, wall saw method, core drill method, etc., and transported by dump truck to an off-site disposal site or temporary storage site where it will be crushed using a breaker to reduce the effects of vibration caused by crushing.

When cutting the concrete, field observation (surveying) will be carried out to monitor the settlement and displacement of the remaining frame. If the amount of displacement or settlement exceeds a pre-set limit, work will be halted and measures will be discussed.

c. Foundation work (pile foundation), boring survey / test pile

The geological boring data conducted during the construction of the No.3 sedimentation basin and filter (45,000 m^3/day) is available. However, since these data are far away from the target facility to be dismantled and the geological conditions may be different, two new investigative borings will be conducted in order to understand the geology at the location of the facility, prepare a dismantling plan, and design the foundation.

d. Temporary construction (prevention of collapse, protection from glass, etc., ensuring safety)

It is possible that strong winds could blow on the scaffolding and shatterproof sheets and cause the scaffolding to collapse. Therefore, the scaffolding must be securely anchored into place. On holidays, in order to prevent the scaffold from collapsing due to strong winds, the shatterproof sheet shall be rolled up and tied to one side of the scaffold so that it is not affected by the wind. Since water is used for cutting concrete, the ground may be disturbed by the caterpillars of machinery, etc. Therefore, drainage channels, iron plate and crushed stone will be installed to prevent such disturbance. When cutting concrete, protective equipment such as safety glasses and dust masks must be used.

In addition, since cutting walls involves work at high places, ensure that working on the scaffold and safety belts are worn to prevent accidents from falling. Since the cut concrete pieces are heavy, when loading them onto dump trucks, be sure to confirm its stability, use appropriate lifting equipment, and use supporting ropes to prevent concrete pieces from swing. In addition, when transporting by dump truck, make sure to observe the maximum authorized payload.

e. Minimize piping / wiring switching (valve operation, temporary piping, wiring removal, etc.)

During detailed design, when demolishing the No. 1 sedimentation basin and Filter in Step 2 and Step 4, it is necessary to decide the procedure so as not to interfere with the facility in use.

4) Design (processing method, etc.) and construction policy

Due to the limited site area, a high-rate coagulation sedimentation basin system similar to No. 3 sedimentation basin and filter (45,000 m^3/day) will be adopted.

5) Existing materials and data available

Since there is almost no data on the No. 1 sedimentation basin and filter (100,000 m^3/day), the designer shall conduct actual measurements at the time of implementation design and make appropriate designs based on the results.

CHAPTER 7 TRANSMISSION AND DISTRIBUTION NETWORK

7.1 EXISTING FACILITIES

7.1.1 Outline of Transmission Network

(1) Transmission Network

The existing transmission network is shown in ***Figure 7.1.1***.

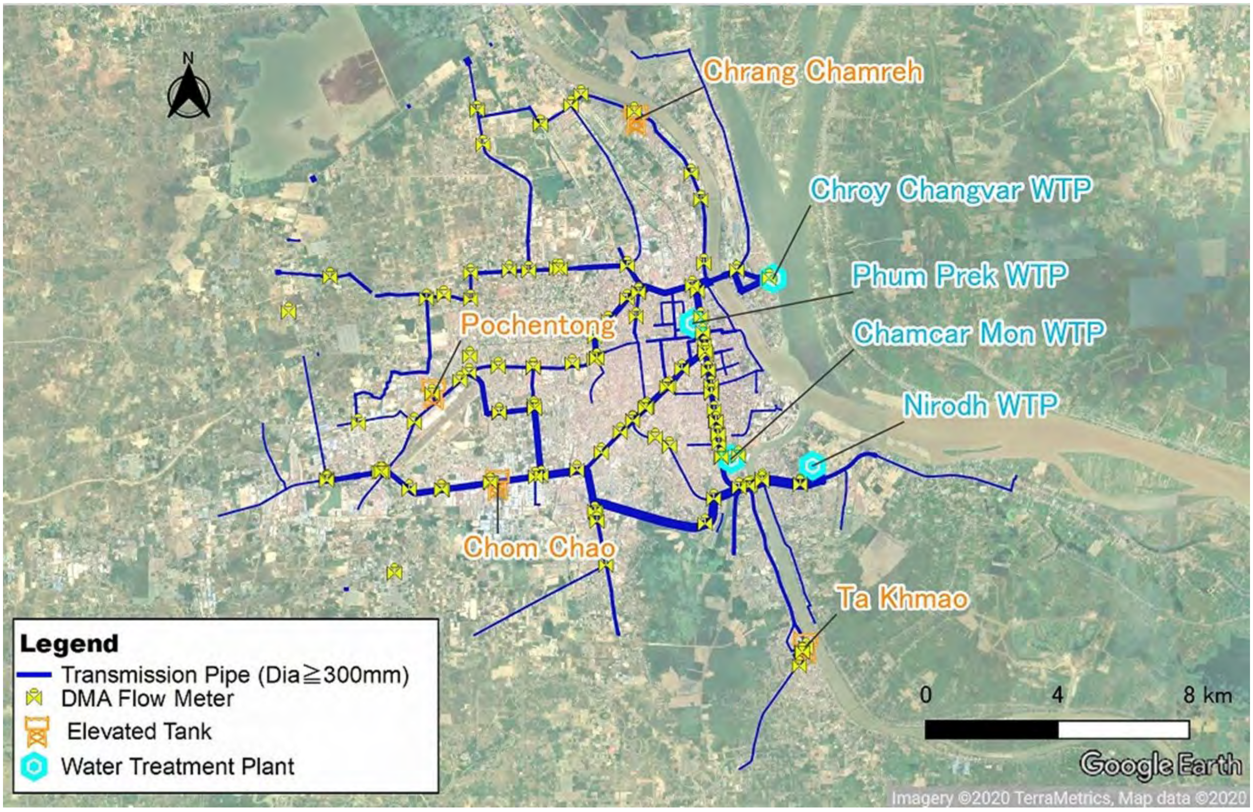


Figure 7.1.1 Outline of Transmission Network
Source: JICA Data Collection Survey Team based on PPWSA GIS data

The existing water supply system consists of four WTPs (Phum Prek WTP, Chroy Changvar WTP, Nirodh WTP, and Chamcar Mon WTP) that are interconnected to supply water in the service area. In some areas, water is delivered to the DMA from an elevated water tank and a water distribution network is constructed within the DMA.

As of 2020, the water pipe networks extending from each WTP are interconnected. The supply system was designed assuming that water would be supplied through this interconnected, mutually flexible system. Therefore, water distribution areas for each WTP have not been clearly defined.

Table 7.1.1 and ***Figure 7.1.2*** show the length of installed pipe. All water pipes of a diameter of 300 mm or more are ductile cast iron pipes.

Table 7.1.1 Outline of Transmission Pipe Length

Diameter	Pipe Length (m)											Total
(mm)	～2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
300	69,666	4,423	1	2,762	3,313	6,187	3,620	1,417	8	2,754	556	94,706
315	3,767	0	0	0	0	0	0	1,092	0	0	0	4,859
350	637	0	0	0	0	0	0	0	0	0	0	637
400	19,143	2,261	2,664	192	2,182	124	2,587	28	26	0	0	29,206
450	3,588	0	0	0	0	0	0	0	0	0	0	3,588
500	24,069	2,296	1,599	7,534	59	1,303	2,460	1,246	0	0	0	40,565
600	5,927	0	0	44	49	0	39	2,592	0	30	0	8,682
700	3,556	0	0	0	0	0	253	0	0	0	0	3,808
800	9,079	0	2	283	857	513	4,161	700	0	0	0	15,594
900	5,059	0	0	0	0	0	0	0	0	0	0	5,059
1000	4,828	1,917	0	0	4,110	129	9	1,953	0	0	0	12,947
1100	1,159	0	0	0	0	0	0	0	0	0	0	1,159
1200	1,721	0	0	1,700	737	0	17	0	0	0	0	4,175
1250	62	0	0	0	0	0	0	0	0	0	0	62
1350	122	0	0	0	0	0	0	0	0	0	0	122
1400	1,036	0	1,042	3,677	501	0	0	0	0	0	0	6,255
1500	31	0	0	0	0	0	0	0	0	0	0	31
1600	5,511	0	0	73	25	0	0	0	0	0	0	5,610
Total	**158,961**	**10,898**	**5,307**	**16,265**	**11,832**	**8,256**	**13,146**	**9,028**	**34**	**2,784**	**556**	**237,066**

Source: JICA Data Collection Survey Team based on PPWSA GIS data

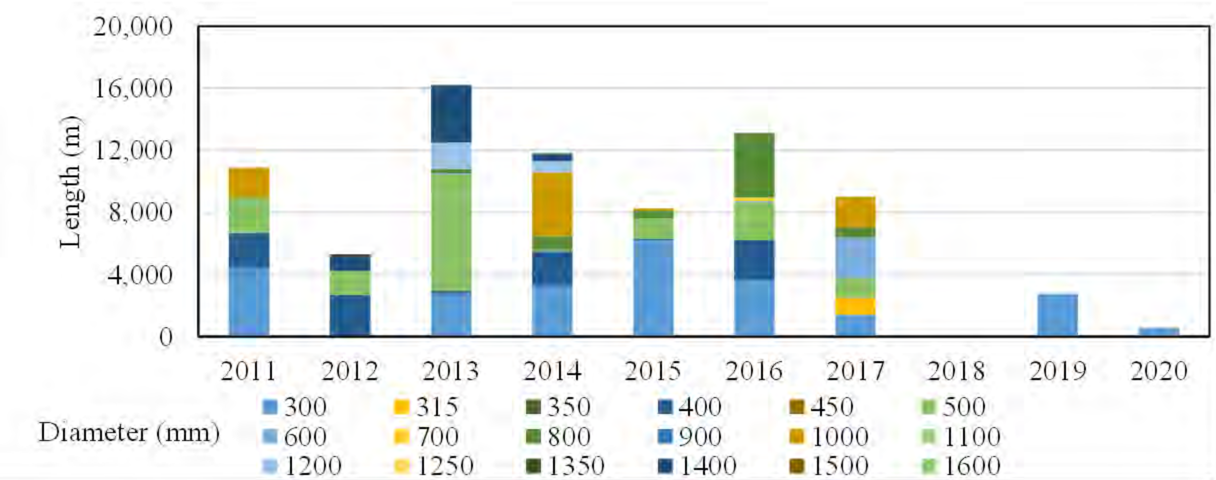


Figure 7.1.2 Installed Pipe Length by Pipe Material
Source: JICA Data Collection Survey Team based on PPWSA GIS data

(2) Elevated Tanks

1) Summary of Elevated Water Storage Tanks

Elevated water tanks were constructed in 2005 and 2009 and are installed in four locations in Phnom Penh. The locations of the elevated tanks are shown in ***Figure 7.1.3***, and details of each are summarized in ***Table 7.1.2***.

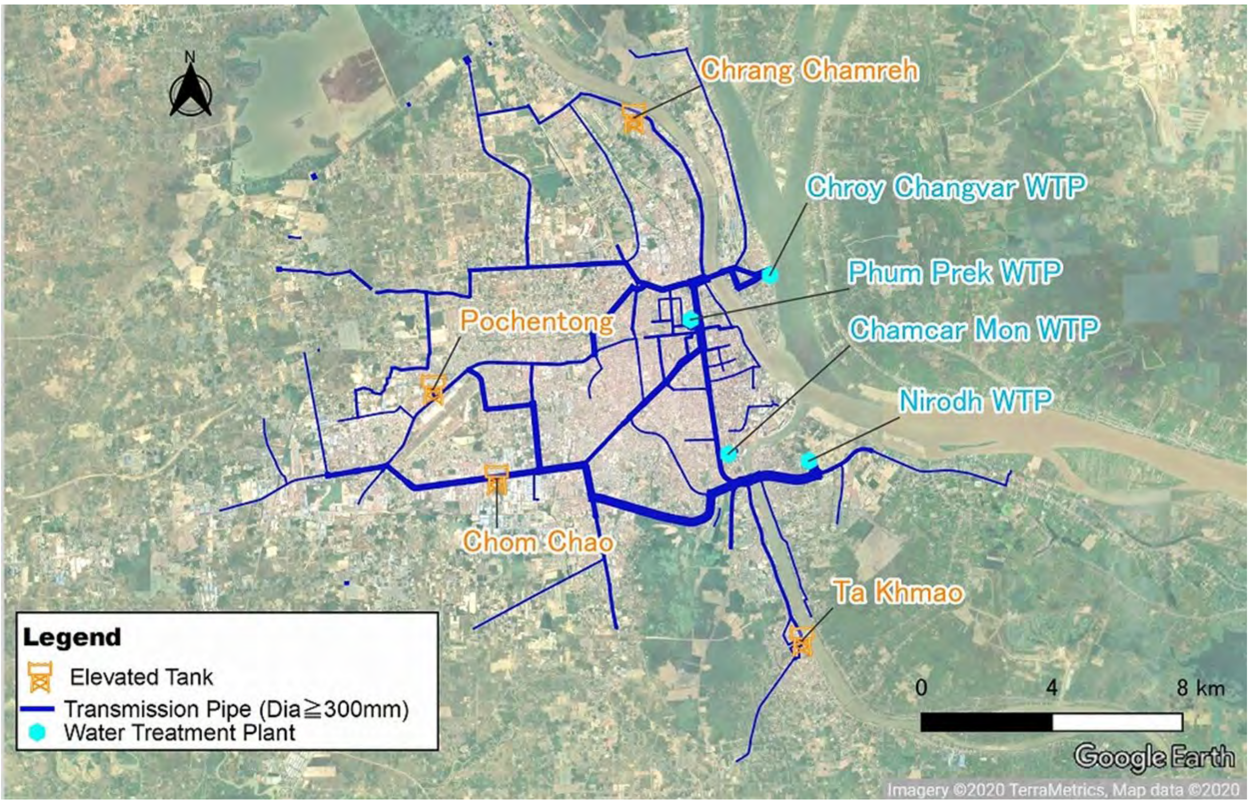


Figure 7.1.3 Location of Elevated Tanks
Source: Survey team based on Third Water Supply Master Plan (2016-2030)

Table 7.1.2 Existing Treated Water Transmission System

Location	Construction Year	Volume (m^3)	HWL (m AMSL)	LWL (m AMSL)
Chrang Chamreh	2005	1,500	41.70	34.80
Chom Chao	2005	1,500	41.70	34.71
Pochentong	2005	1,500	41.70	34.87
Ta Khmao	2009	1,410	36.70	30.20

* m AMSL (Meters Above Mean Sea Level)
Source: JICA Data Collection Survey Team based on Third Water Supply Master Plan (2016-2030)

2) Water Level and Water Pressure of Elevated Water Storage Tanks

Each elevated tank is fitted with a water level gauge and pressure gauge. Water level and pressure are measured every 15 minutes. ***Figure 7.1.4*** shows the annual average water level and the time variation of average water pressure in the elevated tanks.

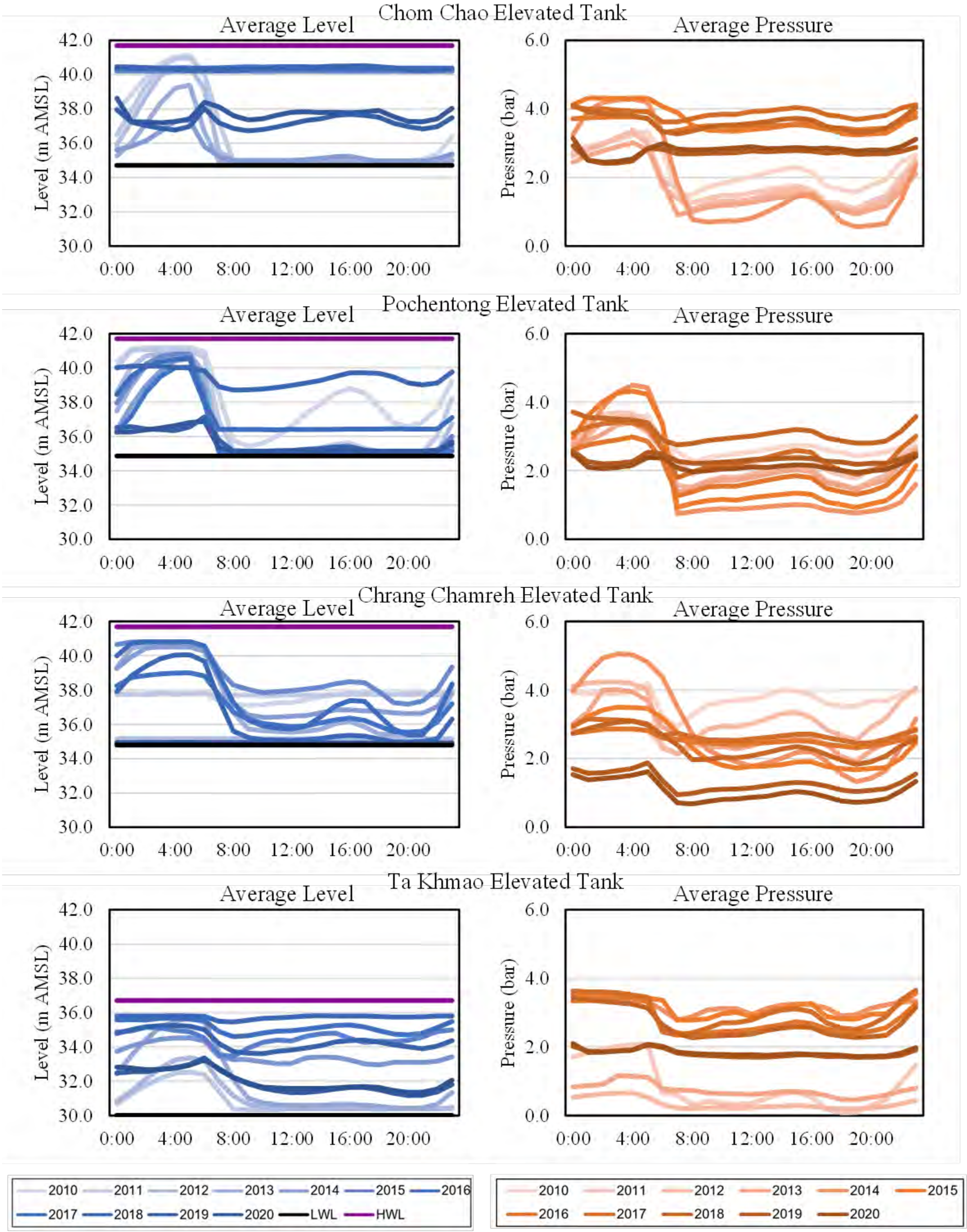


Figure 7.1.4 Average Water Level and Water Pressure of Elevated Water Storage Tanks
Source: JICA Data Collection Survey Team based on PPWSA GIS data

The elevated water tanks were originally designed and built to fill up during the night and distribute water with head pressure to the surrounding area throughout the day. This was the case until around 2014. After that time, due to the increasing population and water demand, most of the stored water would be used up during the morning hours, when demand is greatest. With insufficient water remaining in the elevated tank, it became difficult to maintain pressure in the supply lines for the rest of the day.

In recent years, the elevated tanks have been by-passed and water has been supplied directly to the distribution pipes to maintain pressure during peak usage hours.

(3) Distribution Reservoirs and Distribution Pipes

1) Summary of Distribution Reservoirs

Each WTP also has a distribution reservoir. Specifications of the reservoirs are shown in ***Table 7.1.3***.

Further details are available in ***Chapter 6***.

Table 7.1.3 Existing Treated Water Transmission System

WTP	Reservoir	Volume (m^3)	HWL (m)	LWL (m)
Phum Prek WTP	No.1	10,000	13.20	9.30
	No.2	10,000		
	No.3	5,000		
Chroy Changvar WTP	Elevated No.1	625	31.50	24.60
	Elevated No.2	625		
	Reservoir No.1	2,880	10.70	6.35
	Reservoir No.2	2,880		
	Reservoir No.1/2	18,500	10.70	6.83
Nirodh WTP	Reservoir x 2	11,600	12.80	8.37
	Reservoir x 2	12,260	12.76	8.22
Chamcar Mon WTP	Reservoir x 2	2,400	10.41	5.53

Source: JICA Data Collection Survey Team based on PPWSA GIS data

2) Summary of Transmission Pumps

Specifications of the existing transmission pumps are outlined in ***Table 7.1.4***. Further details are available in ***Chapter 6***.

Table 7.1.4 Outline of Transmission Pumps

WTP	Number of Pump	Flow rate (m^3/h)	Head (m)	Power (kW)
Phum Prek WTP	1-3	2,100	42	320
	4	3,050	46	520
	5-8	1,050	42	180
	9	1,650	47	272
Chroy Changvar WTP	1-3	1,400	46	315
	4-6	1,400	46	250
	7-8	1,400	46	250
Nirodh WTP	1-6	1,800	53	560
	7-12	1,800	53	560
Chamcar Mon WTP	1-4	1,100	46	315

Source: JICA Data Collection Survey Team based on PPWSA GIS data

3) Reservoir Water Pressure and Transmission Volume

Each distribution reservoir is fitted with a flower meter and pressure gauge. Flow rate and pressure are measured every 15 minutes. ***Figure 7.1.5*** shows the average water flow and variation of average water pressure in the WTPs.

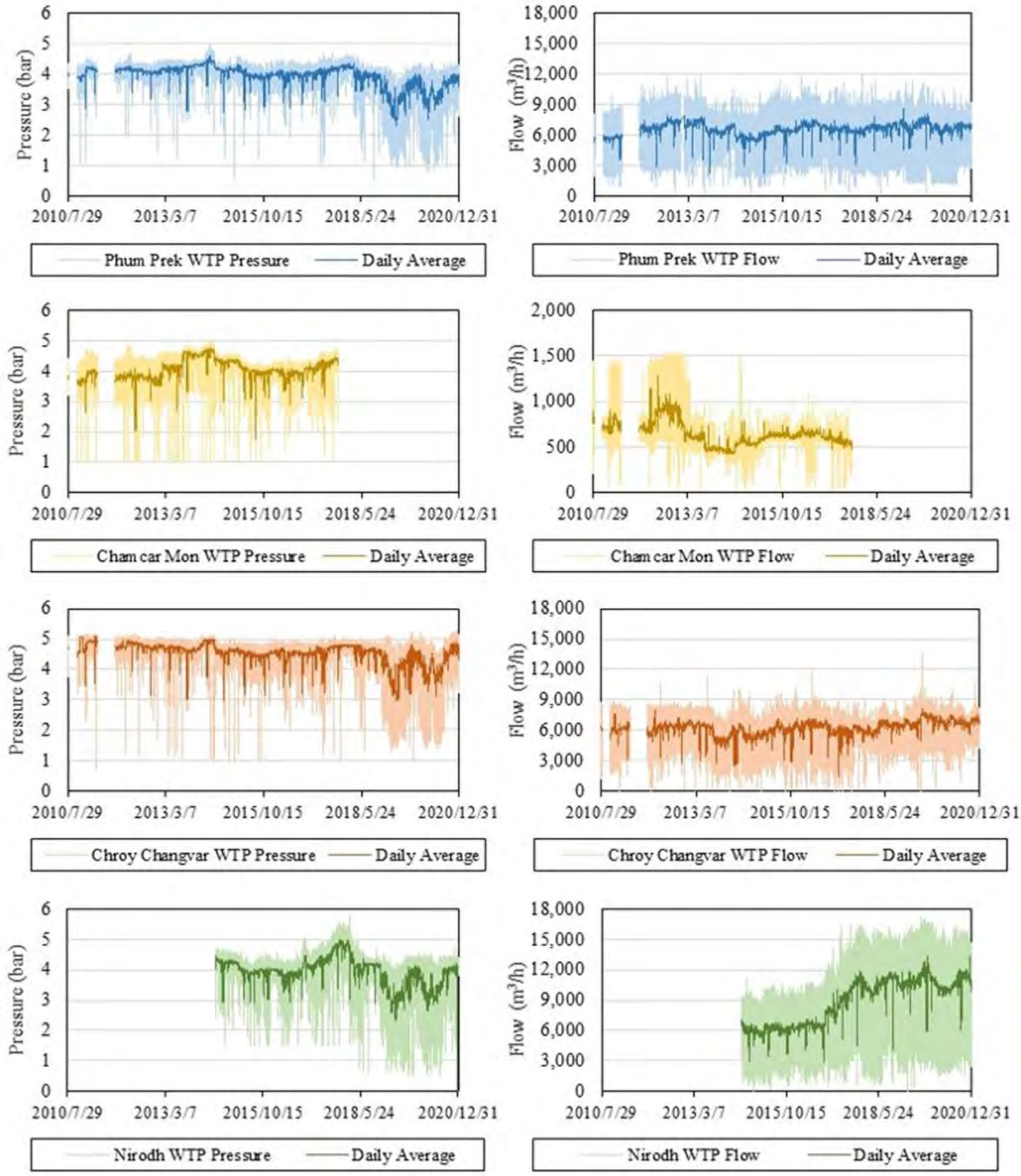


Figure 7.1.5 Reservoir Water Pressure and Transmission Volume
Source: JICA Data Collection Survey Team based on PPWSA GIS data

(4) Supply Area

The water supply area as of 2020 is shown in ***Figure 7.1.6***.

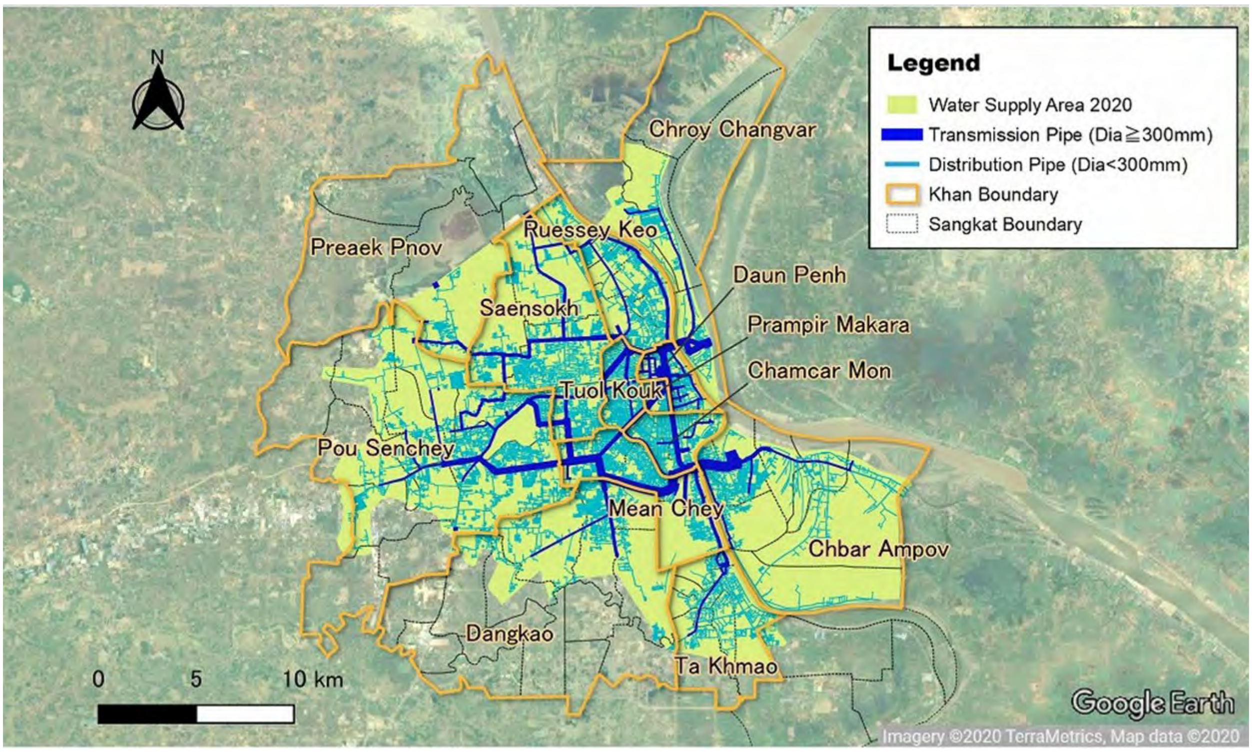


Figure 7.1.6 PPWSA's Water Supply Area, 2020

Source: JICA Data Collection Survey Team based on hearing to PPWSA

The water supply area of PPWSA in 2020 covers the 12 Khans of the Phnom Penh urban area and 13 administrative districts of Ta Khmao City in Kandal province. The total land area is 671 km^2. The land area of each administrative district is shown in ***Table 7.1.5***.

Table 7.1.5 Water Supply Area of Each Administrative District

CODE	KHAN	ADMINISTRATIVE AREA (km^2)	SUPPLY AREA 2020 (km^2)	SUPPLIED AREA RATIO 2020 (%)
01	Daun Penh	6.5	6.5	100
02	Prampir Makara	2.2	2.2	100
03	Chamcar Mon	10.5	10.5	100
04	Tuol Kouk	8.3	8.3	100
05	Ruessey Keo	23.0	23.0	100
06	Mean Chey	24.4	24.4	100
07	Dangkao	121.8	45.3	37
08	Pou Senchey	141.9	84.0	59
09	Saensokh	51.7	51.7	100
10	Chrouy Changvar	68.4	20.8	30
11	Chbar Ampov	74.3	70.1	94
12	Preaek Pnov	106.9	17.1	16
13	Ta Khmao	30.6	22.4	73
	Total	671	386	58

Source: JICA Data Collection Survey Team based on PPWSA GIS data

(5) District Metered Area

1) DMA boundaries

Reconstruction of the District Metered Areas (hereinafter referred to as "DMA") was considered in the Greater Phnom Penh Water Supply System Supervision Upgrade Project in 2015, implemented under AfD support. With the results of the project, PPWSA increased the number of household connections in each DMA from 1,500 to 3,000 and the length of DMA network piping from 15 km to 35 km.

As of 2020, 108 DMAs have been established. The DMAs are shown in ***Figure 7.1.7***.

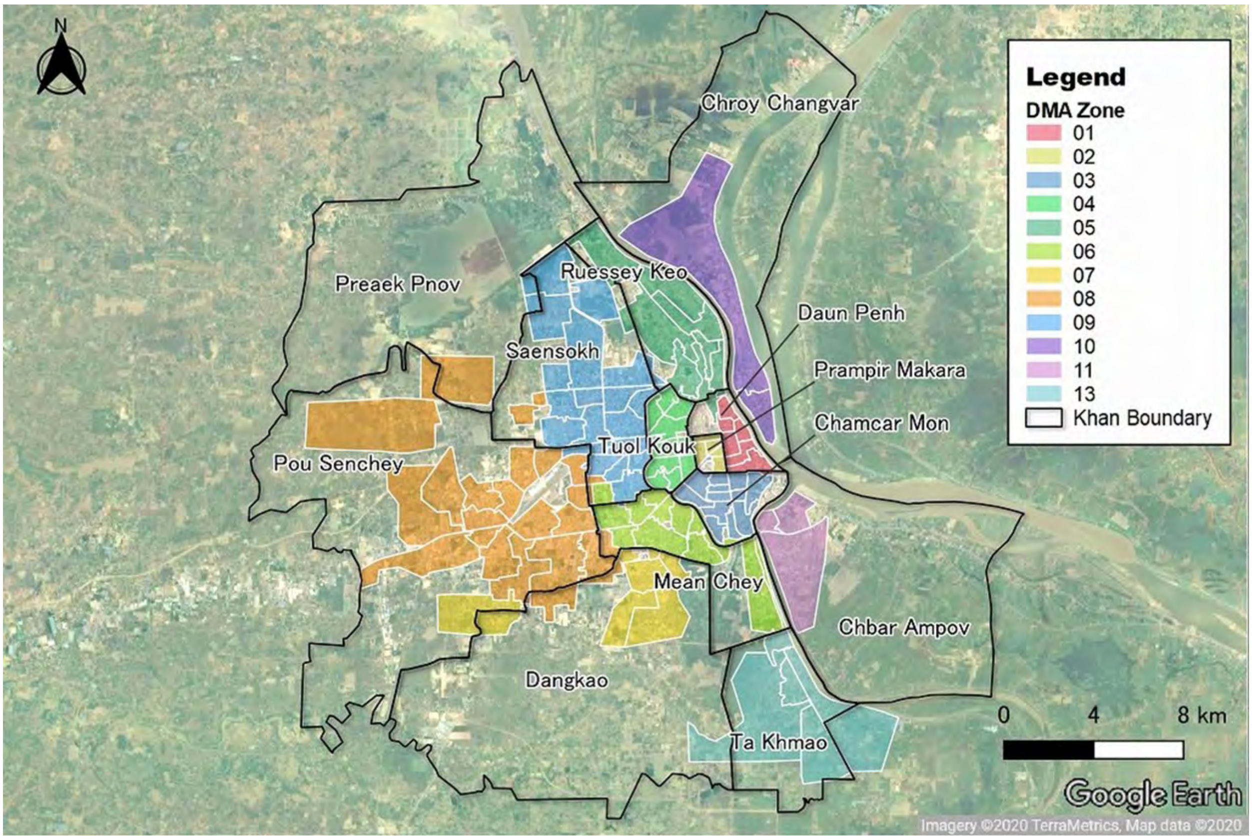


Figure 7.1.7 Outline of DMA (1)
Source: JICA Data Collection Survey Team based on PPWSA GIS data

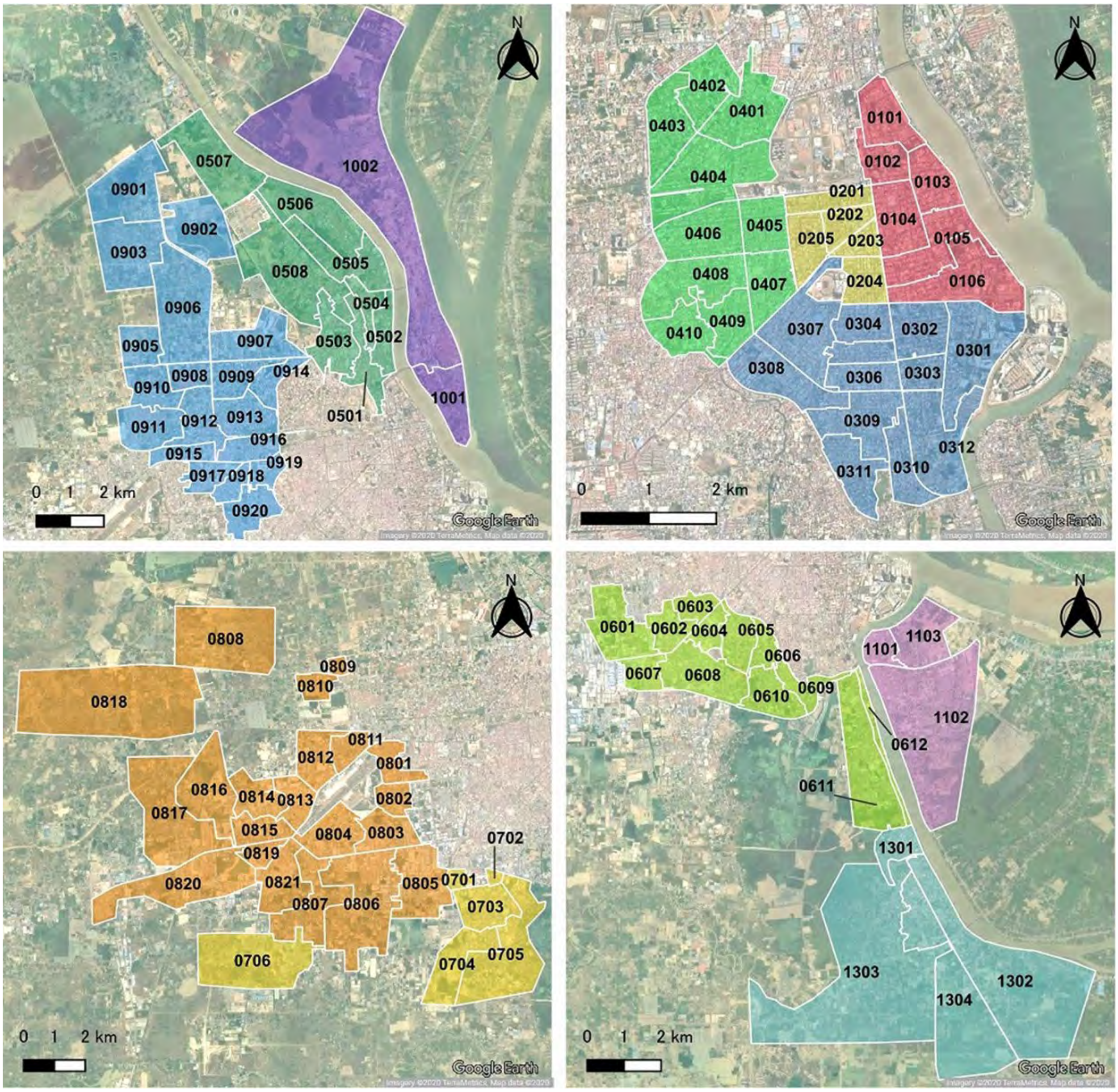


Figure 7.1.8 Outline of DMA (2)
Source: JICA Data Collection Survey Team based on PPWSA GIS data

The DMAs that have been established are modifications of existing DMAs. They do not necessarily conform to the standards set by PPWSA, such as 1,500 to 3,000 connections per DMA, or 15 km to 30 km of transmission lines per DMA. There are several DMAs where connects far exceed these targets.

2) Supply Volume and Pressure of DMAs

The inlet point of each DMA is fitted with a flow meter and water pressure meter which comprise the DMA meter. Readings are taken and recorded every 15 minutes. DMA meter locations are shown in ***Figure 7.1.9***.

Metering records are shown in ***Table 7.1.6*** and ***Figure 7.1.10***.

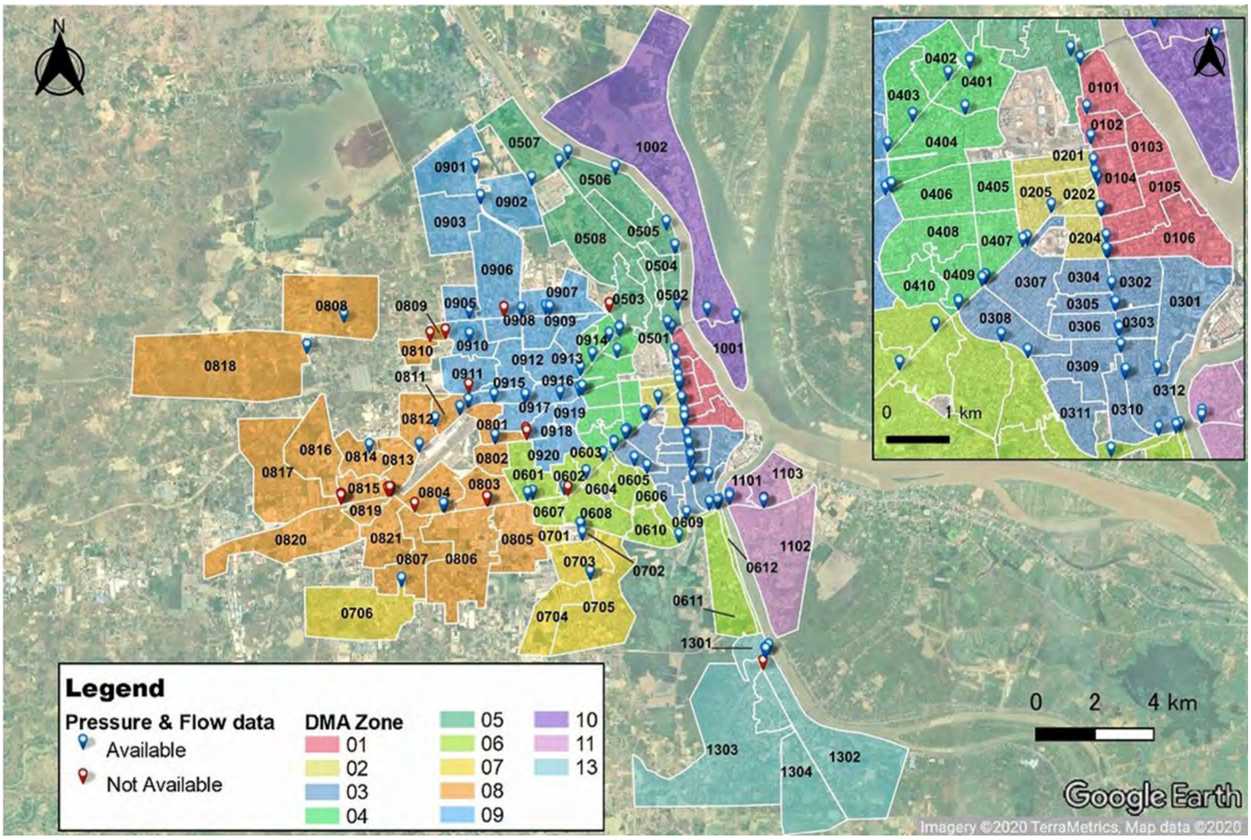


Figure 7.1.9 DMA Meter Locations
Source: JICA Data Collection Survey Team based on PPWSA GIS data

Table 7.1.6 Summary of DMA Meter Records

DMA Code	DMA Ave. Inlet Pressure (bar)	DMA Ave. Inlet Volume (m^3/day)	DMA Elevation (m AMSL)	DMA Code	DMA Ave. Inlet Pressure (bar)	DMA Ave. Inlet Volume (m^3/day)	DMA Elevation (m AMSL)
101	3.7	168	12	702	1.0	12	13
102	3.8	127	13	703	Not Available	Not Available	13
103	4.0	127	12	704	2.8	8	12
104	4.0	478	12	705	2.8	7	12
105	3.6	200	12	706	1.8	66	16
106	3.0	390	12	801	3.1	98	12
201	3.8	108	12	802	Not Available	Not Available	12
202	4.0	240	12	803	Not Available	Not Available	13
203	3.4	174	12	804	Error	266	13
204	3.9	260	12	805	3.5	436	12
205	3.5	196	12	806	3.3	256	13
301	4.0	208	11	807	Not Available	Not Available	14
302	3.1	200	12	808	3.5	32	16
303	3.8	94	11	809	Not Available	Not Available	12
304	4.4	260	11	810	Not Available	Not Available	15
305	4.0	118	11	811	3.1	68	14
306	3.7	174	11	812	2.6	308	14
307	3.8	378	12	813	3.0	174	14
308	3.9	272	13	814	2.5	131	15
309	4.1	344	11	815	Not Available	Not Available	17

DMA Code	DMA Ave. Inlet Pressure (bar)	DMA Ave. Inlet Volume (m^3/day)	DMA Elevation (m AMSL)	DMA Code	DMA Ave. Inlet Pressure (bar)	DMA Ave. Inlet Volume (m^3/day)	DMA Elevation (m AMSL)
310	4.3	178	11	816	2.0	44	16
311	2.0	28	12	817	Not Available	Not Available	17
312	4.0	254	11	818	2.1	36	15
401	3.0	616	13	819	Not Available	Not Available	15
402	3.4	106	13	820	Not Available	Not Available	17
403	3.4	144	13	821	Not Available	Not Available	15
404	1.8	352	13	901	2.5	58	13
405	3.7	302	13	902	Error	30	10
406	3.0	122	13	903	2.0	88	10
407	3.0	204	13	905	3.2	128	15
408	3.3	288	13	906	Not Available	Not Available	12
409	3.9	220	13	907	3.0	184	12
410	3.3	406	12	908	2.8	220	13
501	3.7	230	13	909	3.4	222	11
502	3.0	602	14	910	2.1	52	14
503	3.0	418	13	911	Not Available	Not Available	14
504	2.0	142	12	912	2.6	47	13
505	2.3	302	12	913	3.0	345	13
506	1.5	242	12	914	Not Available	Not Available	12
507	2.1	138	12	915	2.0	186	14
508	1.9	160	10	916	4.0	196	14
601	4.2	348	12	917	Error	56	13
602	2.5	200	12	918	Not Available	Not Available	12
603	3.0	128	13	919	3.2	36	13
604	4.0	254	13	920	Not Available	Not Available	12
605	2.5	342	12	1001	1.8	161	11
606	2.1	28	13	1002	4.0	458	11
607	3.0	72	11	1101	4.0	152	13
608	Not Available	Not Available	11	1102	Error	341	14
609	3.0	272	11	1103	Not Available	Not Available	15
610	Not Available	Not Available	11	1301	2.3	440	12
611	3.9	387	13	1302	2.0	386	11
612	Error	82	12	1303	2.0	280	11
701	3.4	74	13	1304	Not Available	Not Available	12

*Not available denotes data is not available from PPWSA. Error denotes that although data is available, there are many missing entries or anomalous entries.
Source: JICA Data Collection Survey Team based on PPWSA GIS data

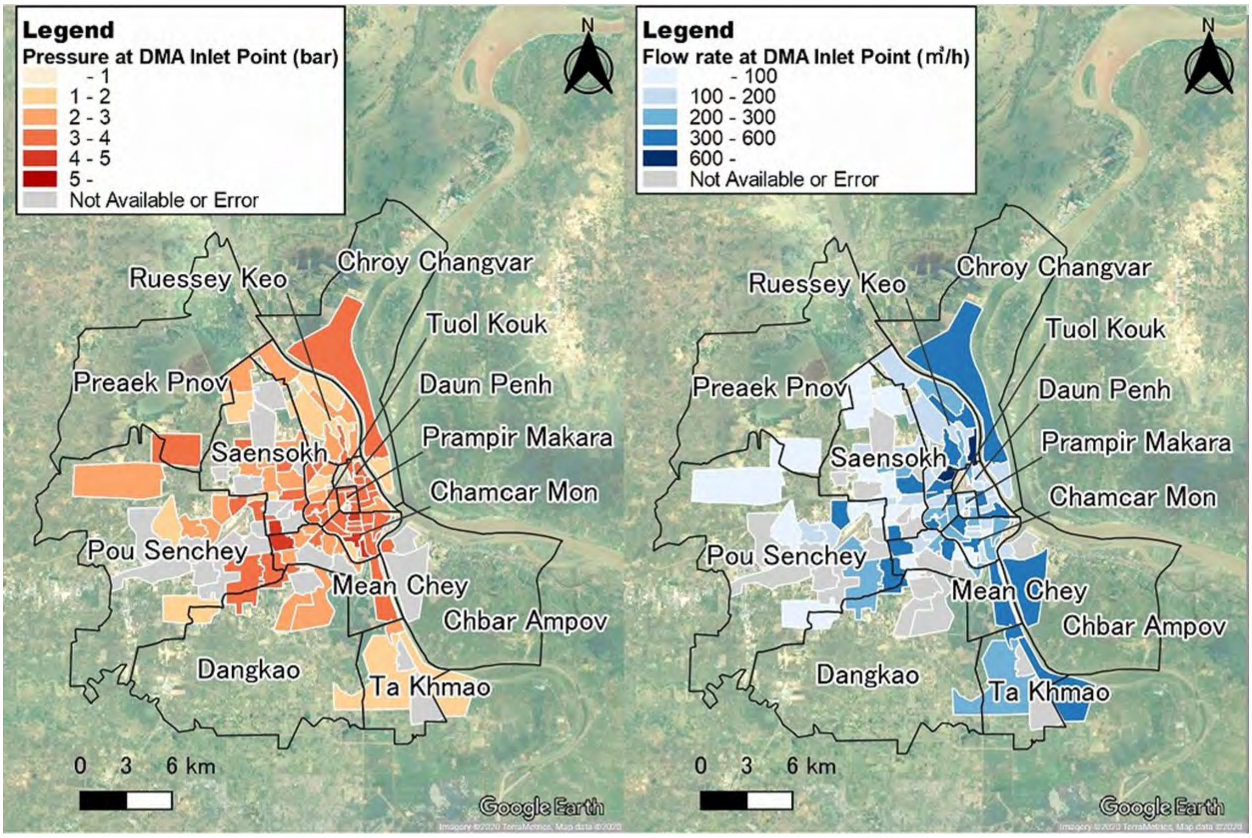


Figure 7.1.10 Water Pressure and Volume Distribution Within Each DMA
Source: JICA Data Collection Survey Team based on PPWSA GIS data

To ensure sufficient pressure to all points within the DMA, an inlet pressure of 3 bar is desired. However, with the exception of central Phnom Penh (Khan Daun Penh, Khan Prampir Makara, Khan Chamcar Mon, and Khan Tuol Kouk), the average inlet pressure tended to be below 3 bar. The inlet volume from 2017 to 2020 was lower than the planned amount due to water restrictions caused by construction of WTPs.

Time variance of pressure and flow of each DMA is shown in ***Figure 7-1.11*** and ***Figure 7.1.12***.

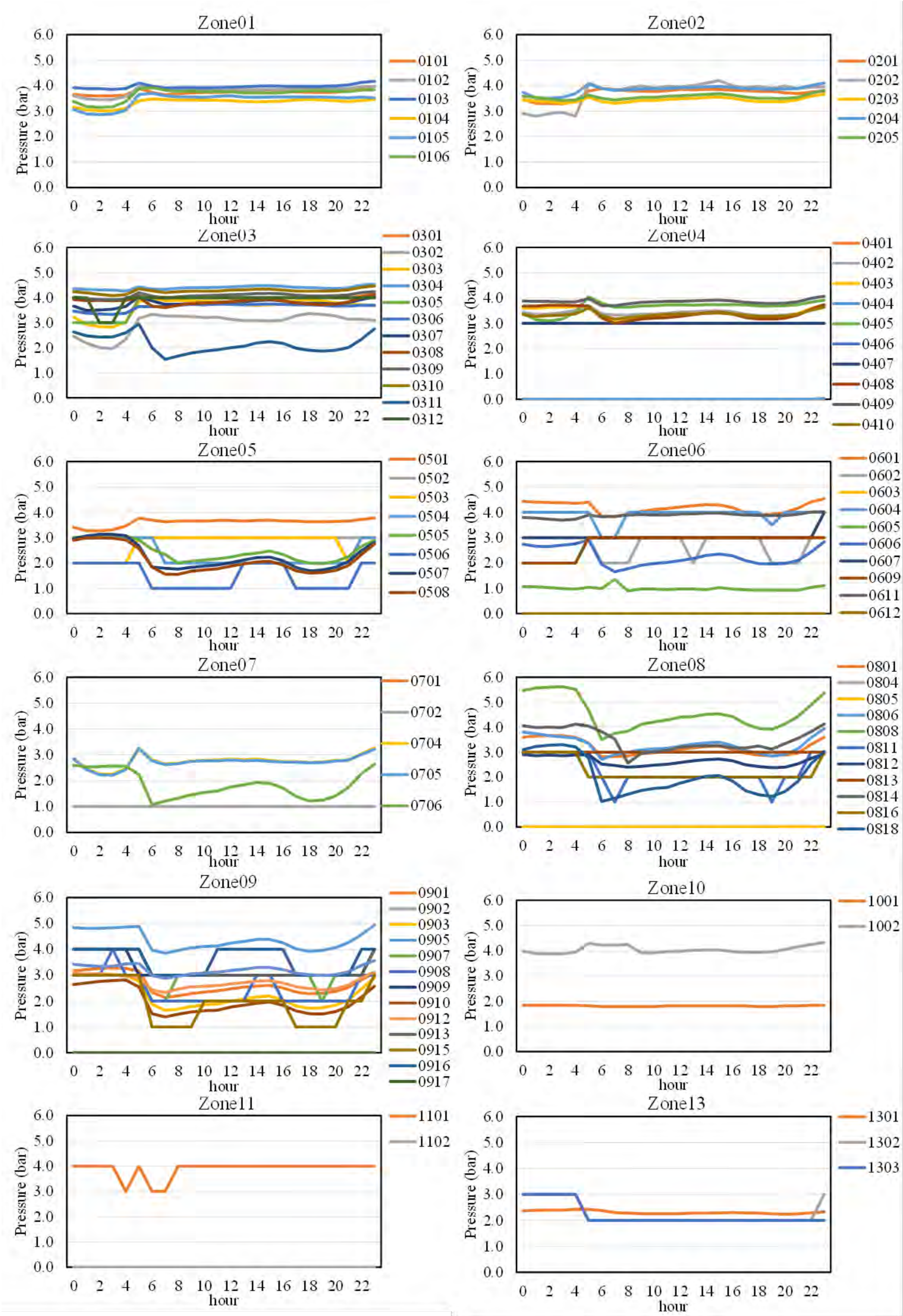


Figure 7.1.11 Water Pressure of Each DMA

*Water flow and pressure data are average values from 2017 to 2020
Source: JICA Data Collection Survey Team based on PPWSA GIS data

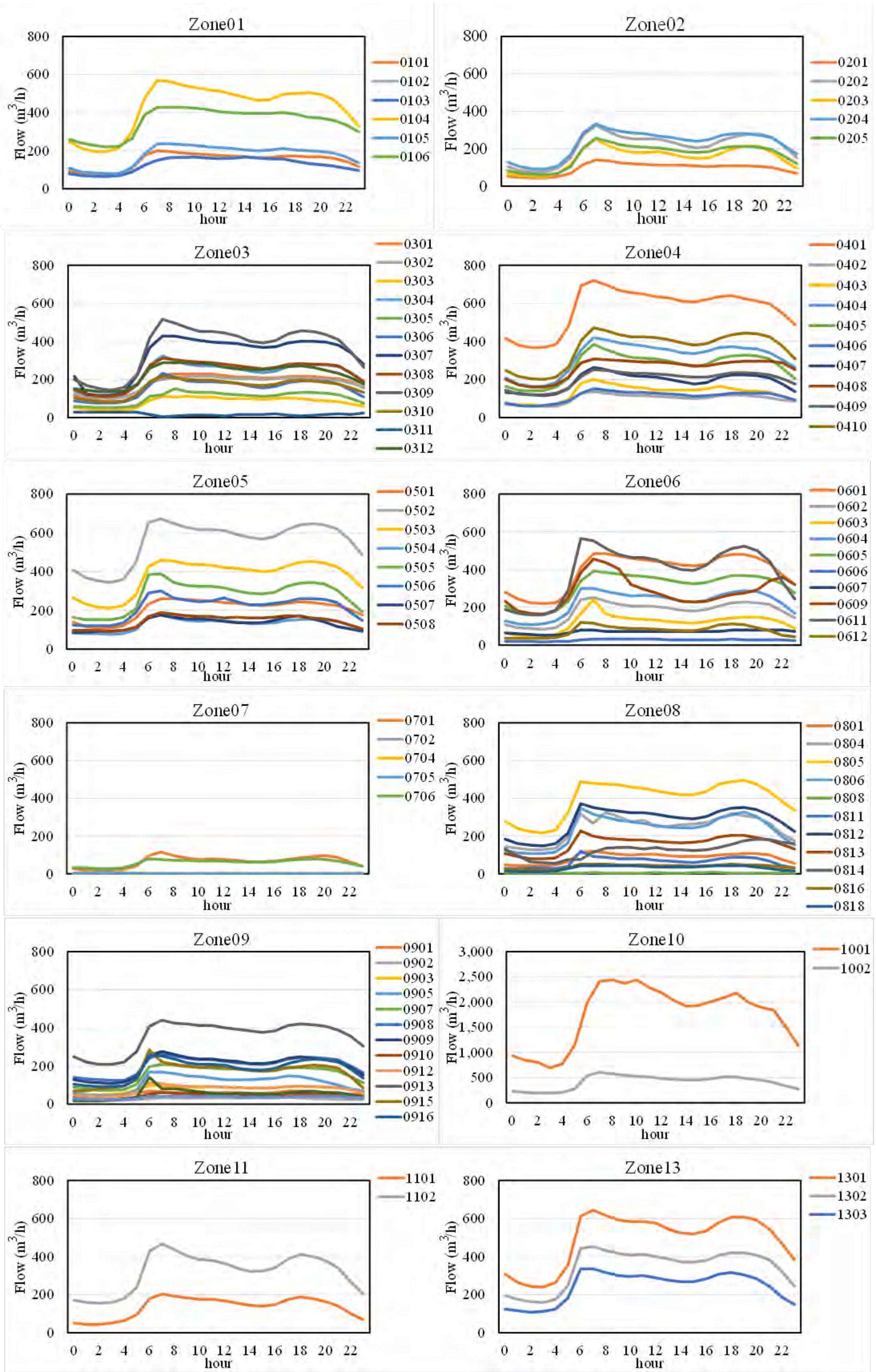


Figure 7.1.12 Water Flow of Each DMA

*Water flow and pressure data are average values from 2017 to 2020

Source: JICA Data Collection Survey Team based on PPWSA GIS data

7.1.2 Distribution Network

(1) Distribution Network

The distribution network is outlined in ***Figure 7.1.13***. Pipeline length by pipe material is shown in ***Figure 7.1.14***.

The distribution pipes create networks within each DMA. Over 95% of the network is made of HDPE.

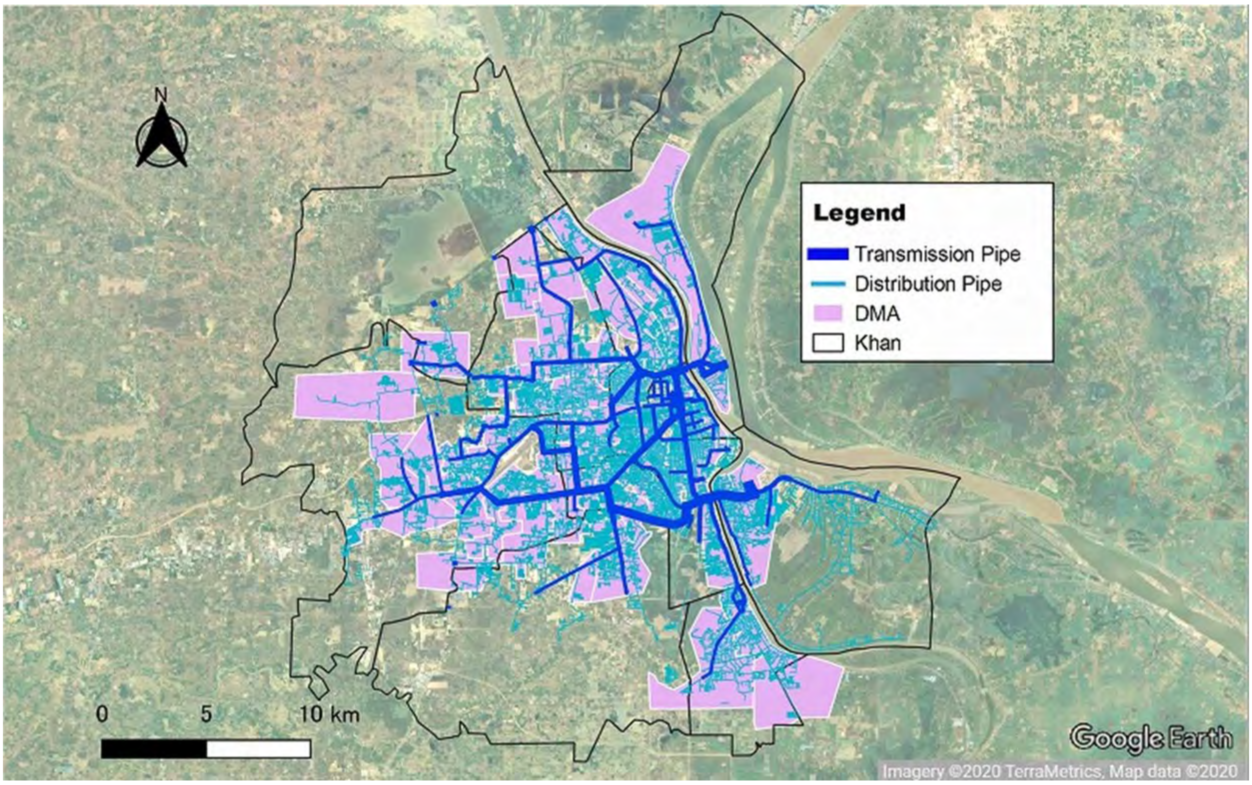


Figure 7.1.13 Outline of Distribution Network
Source: JICA Data Collection Survey Team based on PPWSA GIS data

Table 7.1.7 Outline of Transmission Pipe Length

Diameter	Pipe Length (km)											Total
(mm)	～2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
50	6.6	0	0.6	0.5	0.5	1.4	0	0	0	0	0	9.6
63	270.2	28.7	6.2	23.1	32.6	23	32.9	39	32.6	26.9	8.2	523.4
90	249.1	33	29	28.6	34.8	33.9	36.6	50.6	50.3	58.2	51	655.1
100	38.7	0	0	0	0	0	0	0	0	0.3	0	39
110	486	31.2	37.1	41.1	53.5	36.3	58.7	56.4	62.1	61.4	33.5	957.3
150	43.1	0	0	0	0	0	0	0	0	0.7	0	43.8
160	254.7	16.1	17.9	31.6	27.9	21.9	36.9	34.9	42.2	50.1	18.3	552.5
200	62.1	0	0	0.1	0.1	0.1	0	0	0	0	0	62.4
225	112.5	9.6	10.7	14.7	9.1	21.2	17.7	22.9	22.8	24.4	9.4	275
250	80.3	2	0.1	3.1	1.7	4.6	1.3	1.7	2.4	2.3	0	99.5
Total	1603.3	120.6	101.6	142.8	160.2	142.4	184.1	205.5	212.4	224.3	120.4	3217.6

Source: JICA Data Collection Survey Team based on PPWSA GIS data

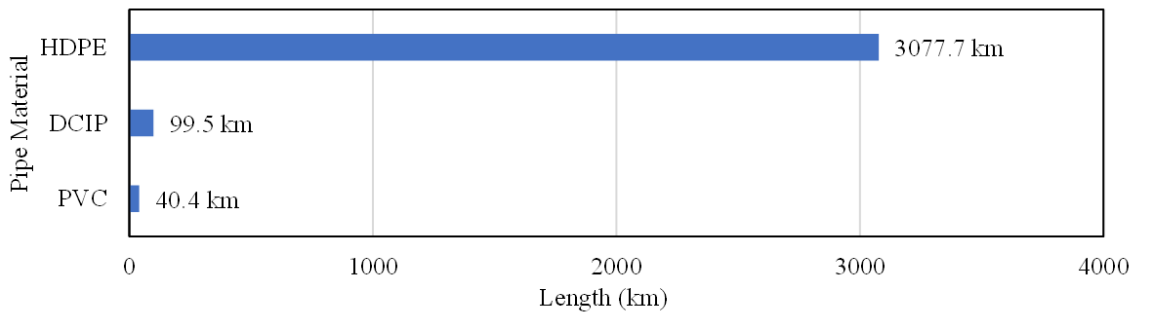


Figure 7.1.14 Transmission Pipe Installation Length by Type
Source: JICA Data Collection Survey Team based on PPWSA GIS data

(2) Transfer of Infrastructure from Private Suppliers

Water distribution lines taken over from Private Water Suppliers is shown in ***Figure 7-1.13***.

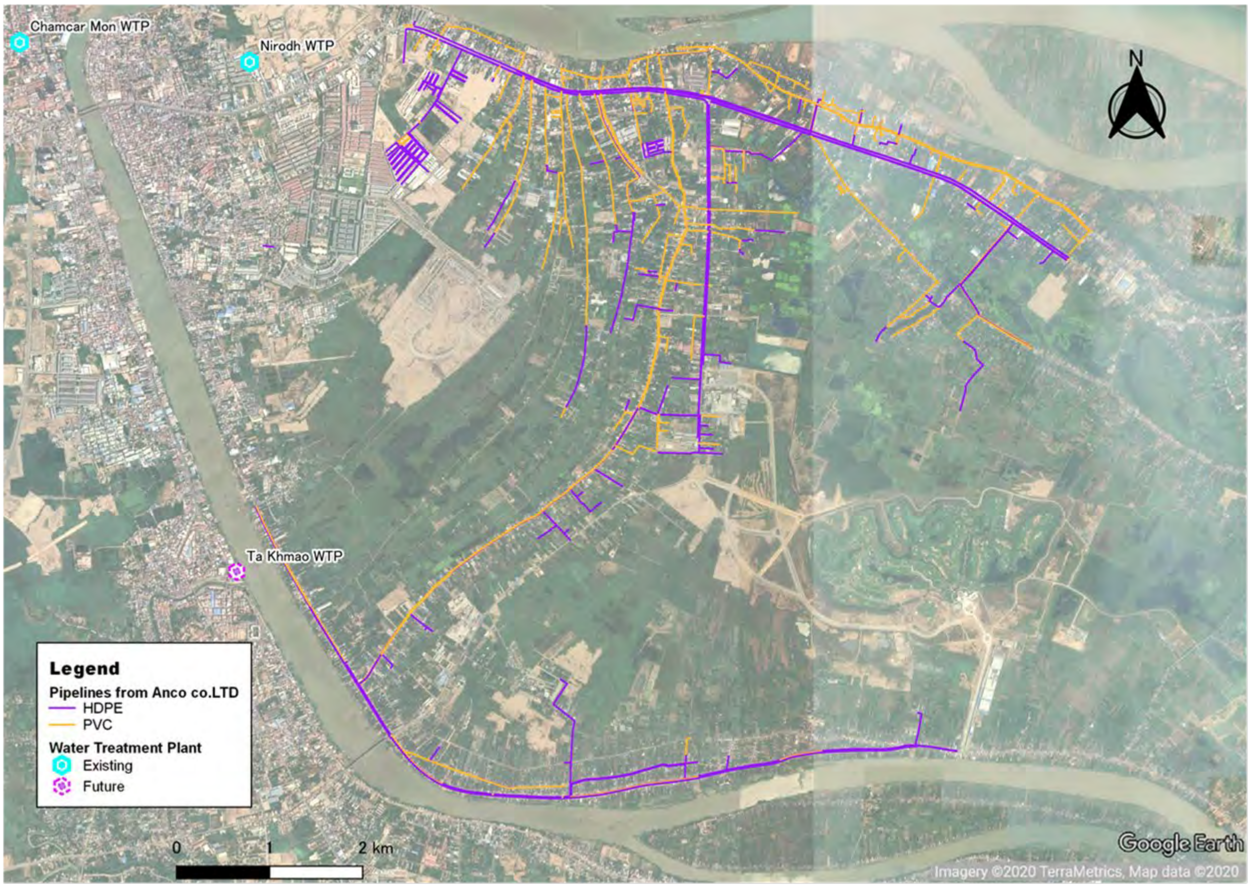


Figure 7.1.15 Area Transferred from Anco Co. to PPWSA in 2018
Source: JICA Data Collection Survey Team based on PPWSA GIS data

In this area (Khan Chbar Ampov) a private company (Anco Co. Ltd.) obtained a license for water supply and started supplying water to the Khan in 2016. However, water supply operations were transferred to PPWSA in 2018 and the area became a part of the PPWSA water supply area. The private operation used its own standards for facility design and construction which lead to inadequate water pressure and quality, and numerous leaks. In order to improve the conditions, PPWSA is working to improve the situation by finding and fixing leaks and replacing existing pipes.

(3) Large Volume Consumers

Large volume users are listed in ***Table 7.1.8***. Their locations are shown in ***Figure 7.1.16***. PPWSA classifies users connected to 100 mm or larger connections as large volume users.

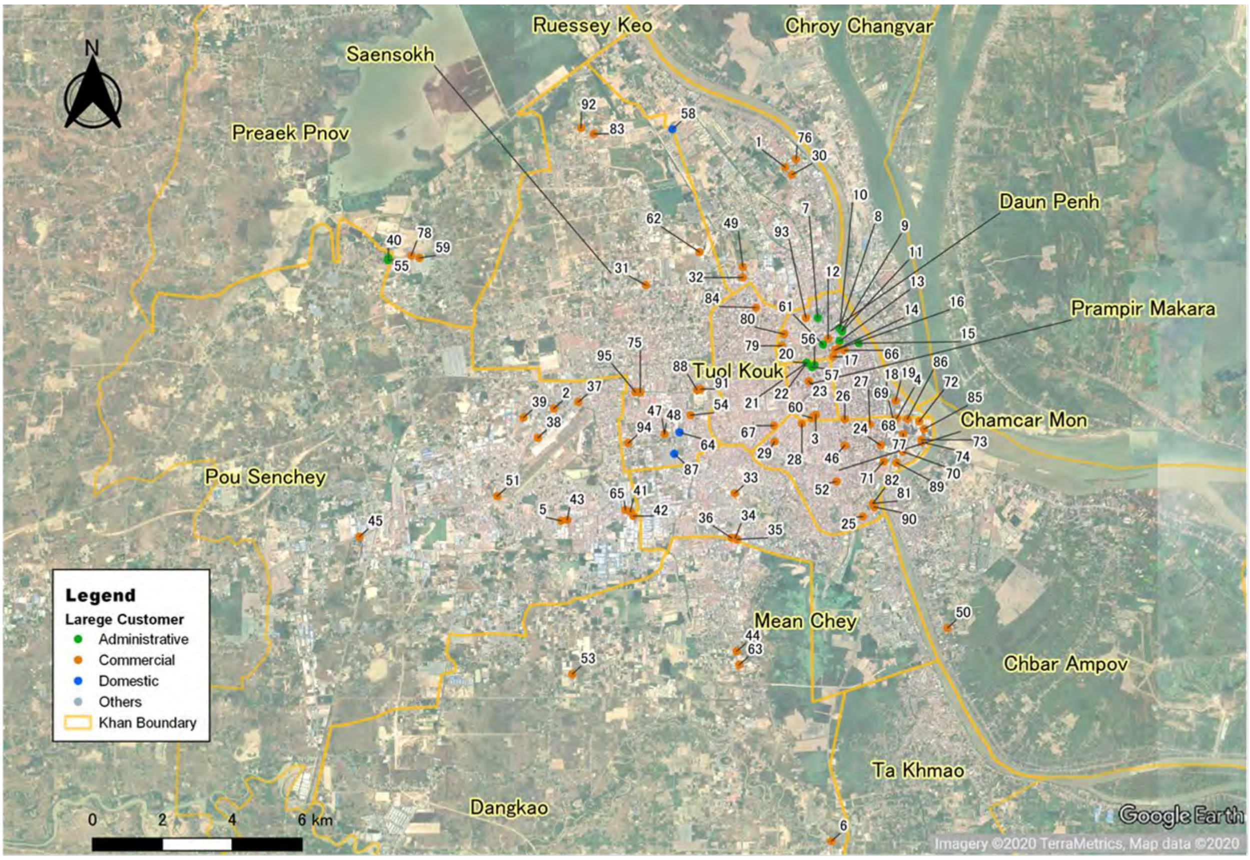


Figure 7.1.16 Location of Large Volume Consumers

Source: JICA Data Collection Survey Team based on PPWSA GIS data

Table 7.1.8 List of Large Volume Consumers

No	CUSTOMER NAME	CATEGORY	No	CUSTOMER NAME	CATEGORY
1	Beer & Beverage Companies	Commercial	49	Camko City	Commercial
2	Business Center and Hotel	Commercial	50	Ice factory	Commercial
3	Olympic Condo	Commercial	51	PPM Pharmaceutical Enterprise	Commercial
4	Jinfu (Naga Company)	Commercial	52	Zhang Sun Li Condo	Commercial
5	Crown Beverage Keys (Cambodia)	Commercial	53	Crown Brewery	Commercial
6	Kerry World Bridge Logistics	Commercial	54	Ice Factory	Commercial
7	Calmette Hospital	Administrative	55	Cambodia-Thailand Professional Development Center	Administrative
8	National Center for Maternal and Child Health	Administrative	56	Office of the Council of Ministers	Administrative
9	Preah Keto Mealea Hospital	Administrative	57	Office of the Council of Ministers	Administrative
10	Maternal and Child Health Center	Administrative	58	Fire Extinguisher (Borey Vimean Phnom Penh	Domestic
11	Kantha Bopha I Hospital	Administrative	59	Chheng Sokuntheavy (Fruit Factory)	Commercial
12	Le Royal Hotel	Commercial	60	Lim Sina Condo	Commercial
13	Ministry of Economy and Finance	Administrative	61	Ministry of Posts	Administrative
14	US Embassy	Commercial	62	Aeon Mall (Cambodia) Co., Ltd.	Commercial
15	Ministry of Posts	Administrative	63	Khmer Breweries Co., Ltd.	Commercial
16	Vattanac Property Ltd.	Commercial	64	Fire Orchid Fire Extinguisher	Domestic
17	Canadia Tower	Commercial	65	Canadia Industrial Park	Commercial
18	Royal Palace	Administrative	66	Hong Kong Lane (Premium Investment)	Commercial
19	Cambodiana	Commercial	67	Seng Saran (Doeum Kor Market	Commercial
20	Office of the Council of Ministers	Administrative	68	Chen Yepern (Tan Sri Chen Ine)	Commercial
21	Office of the Council of Ministers	Administrative	69	Touch Samnang	Commercial
22	Office of the Council of Ministers	Administrative	70	Concrete Silo	Commercial

No	CUSTOMER NAME	CATEGORY	No	CUSTOMER NAME	CATEGORY
23	Julina Hotel	Commercial	71	Rose Condo	Commercial
24	Aeon Mall	Commercial	72	Festival	Commercial
25	PRINCE HAPPINESS PLAZA	Commercial	73	City Hall	Commercial
26	Heng Haing Meng (Mr. Hun Lucky Molly)	Commercial	74	New Golf Club	Commercial
27	Embassy Place Apartments	Commercial	75	Sung Houy Property Development	Commercial
28	Olympic Market Representative	Commercial	76	Breweries & Beverages	Commercial
29	The Great Duke Hotel	Commercial	77	THE BRIDGE	Commercial
30	Breweries & Beverages	Commercial	78	Vital Pure Water Enterprise	Commercial
31	National Bank of Cambodia	Commercial	79	Great City Company Limited	Commercial
32	World City Co. LTD	Commercial	80	Great City Company Limited	Commercial
33	Neak Hoang 2 Garment Factory	Commercial	81	CENTRAL PLAZA (condo)	Commercial
34	Vong Horn Meng (R / C)	Commercial	82	PLAZA OF TAIZI (condo)	Commercial
35	Vong Hong Meng - Garment Factory	Commercial	83	AC Business Institute	Commercial
36	Ice factory	Commercial	84	Star Ting International	Commercial
37	SCA Company	Commercial	85	Ji Seang Investment Cambodia	Commercial
38	Societe concessionair aeroport	Commercial	86	Sunwa Property Co., Ltd.	Commercial
39	MASTERTEX CAMINTERNATINALCO LT	Commercial	87	Fire Extinguisher (Orchid Villa)	Domestic
40	National Polytechnic Institute of Cambodia	Administrative	88	Prince Real Estate Cambodia Co., Ltd.	Commercial
41	Suntex Pte Ltd (Tailor)	Commercial	89	Sin Thean Chean Company	Commercial
42	D'LUXE INTERNATIONAL CO.,LTD	Commercial	90	Yang Sophing	Commercial
43	Nguon Vuthy Company	Commercial	91	Rumduol Overseas Co., Ltd.	Commercial
44	Khmer Brewery	Commercial	92	Tan Bunsour (Ice Factory)	Commercial
45	Jinfu Garment Factory	Commercial	93	PPCCES PPCCES Company	Commercial
46	City Park Condo	Commercial	94	Spring CJ Company	Commercial
47	Cambodia International School	Commercial	95	Sung Houy Property Development	Commercial
48	Northbridge Development Co.LTD	Commercial			

Source: JICA Data Collection Survey Team based on PPWSA GIS data

(4) Water Pressure of Distribution Lines

PPWSA monitors water pressure within each DMA by monitoring pressure in branch distribution mains. Results of water pressure monitoring are shown in ***Table 7.1.9***. Monitoring locations are shown in ***Figure 7.1.17***.

Table 7.1.9 Analysis of Distribution Pressure

Location		Maximum Pressure (bar)	Average Pressure (bar)
P1	St.200R-Khan Ruessey Keo-Sangkat Ruessey Keo	2.35	1.17
P2	St.103C-Khan Tuek Thla-Sangkat Saen Sok	2.70	1.39
P3	St.58D-Khan Dangkao-Sangkat Dangkao	3.17	1.58
P4	St.W22-Khan Chak Angreae Kraom-Sangkat Mean Chey	2.66	1.33
P5	St.351-Khan Nirodh-Sangkat Chbar Ampov	3.31	1.83
P6	St.2A51- Khan Kantouk-Sangkat Pou Senchey	1.82	0.91
P7	St.30AK-Khan Khmuonh-Sangkat Saen Sok	2.30	1.15
P8	St.148R-Khan Svay Pak-Sangkat Ruessey Keo	2.30	1.15
P9	St.143CC-Khan Porng Tuek-Sangkat Dangkao	3.62	1.81
P10	St.250-Khan Ta Khmao-Sangkat Krong Ta Khmao	2.25	1.12
P11	St.410K-Khan Kraing Thnung-Sangkat Saen Sok	2.23	1.11
P12	St.467K-Khan Kouk Roka-Sangkat Preaek Phnov	1.81	0.90
P13	St.104CW-Khan Prek Leab -Sangkat Chroy Changvar	3.40	1.70
P14	St.110-Khan Chom Chao-Sangkat Pou Senchey	1.74	0.89
P15	NR 1-Khan Prek Eng -Sangkat Chbar Ampov	2.95	1.55

Source: JICA Data Collection Survey Team based on PPWSA GIS data

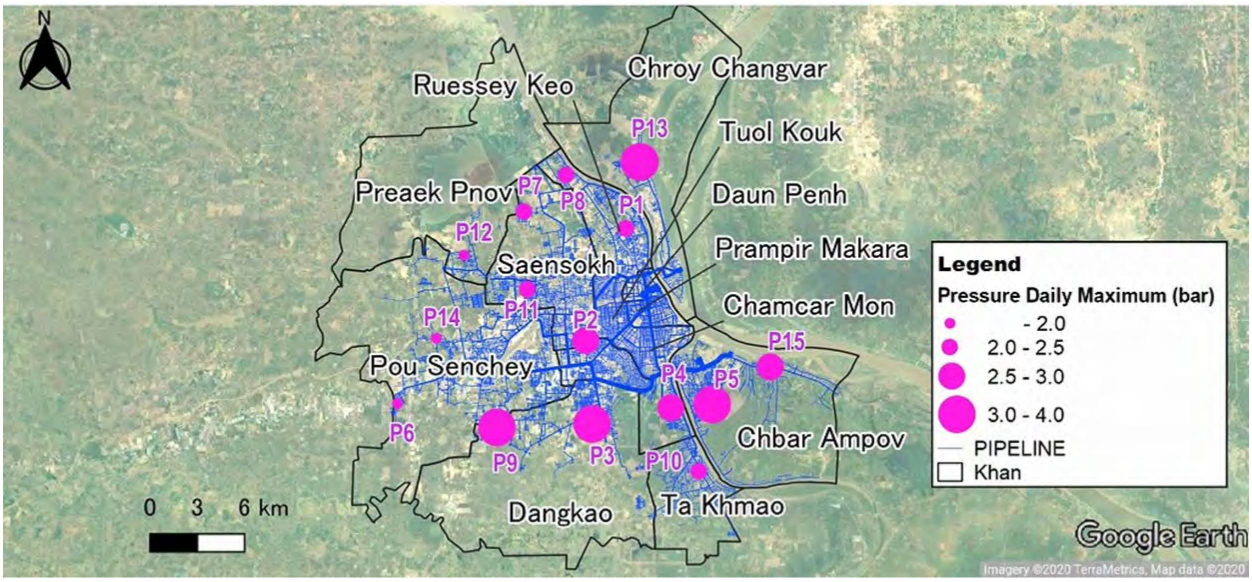


Figure 7.1.17 Branch Pressure Monitoring Locations
Source: JICA Data Collection Survey Team based on PPWSA GIS data

According to water pressure records at the distribution branches, Phan Preaek Pnov (p12) and Khan Pou Senchey (p6, p14) had low pressures.

(5) Standpipe Water Quality

PPWSA monitors water quality by sampling from 30 locations throughout the city every month. Items required in the NDWQS (temperature, pH, turbidity, color, conductivity, residual chlorine, coliform) are analysed. All sample locations satisfy turbidity (5 < NTU), free available chlorine (0.1 ~ 1.0 mg/l) requirements and demonstrates that PPWSA is supplying water that has been properly treated and disinfected.

7.1.3 Operation and Maintenance of Transmission and Distribution Network

(1) Maintenance System and Tasks for Transmission Mains

The maintenance of the transmission mains is shared between the Department of Planning and Projects, Department of Production and Distribution, and the Department of Water and Sanitation Subsidiary Service Branch. Details of the roles are given in ***Chapter 9***.

1) Department of Planning and Project

The Department of Planning and Project manages piping work and planning, GIS data, and daily inspections and records. Water Supply Management Office was established and manages GIS data, plans development of distribution lines, and monitors flow and pressure of WTPs, elevated tanks, DMAs, etc.

2) Department of Production and Distribution

The Department of Production and Distribution repairs pipes and valves, investigates leaks, and manages DMA meters.

3) Department of Water and Sanitation Subsidiary Service Branch

The Department of Water and Sanitation Subsidiary Service Brand repairs pipes. GIS data is updated by each department, and the up-to-date data is comprehensively managed by the Department of Planning and Project.

(2) Preparation and Utilization of Standard Operation Procedures

PPWSA has prepared Standard Operating Procedures documentation (hereinafter referred to as "SOPs") for maintenance works.

Procedures for GIS data recording, management, and storage, methods for O&M of facilities, etc. are the major SOPs. Although operational activities are recorded and stored according to the SOPs, analysis and evaluation of the accumulated data and creations of new procedures is an ongoing issue.

(3) Leakage Conditions

Leakage conditions are outlined in ***Figure 7.1.18***.

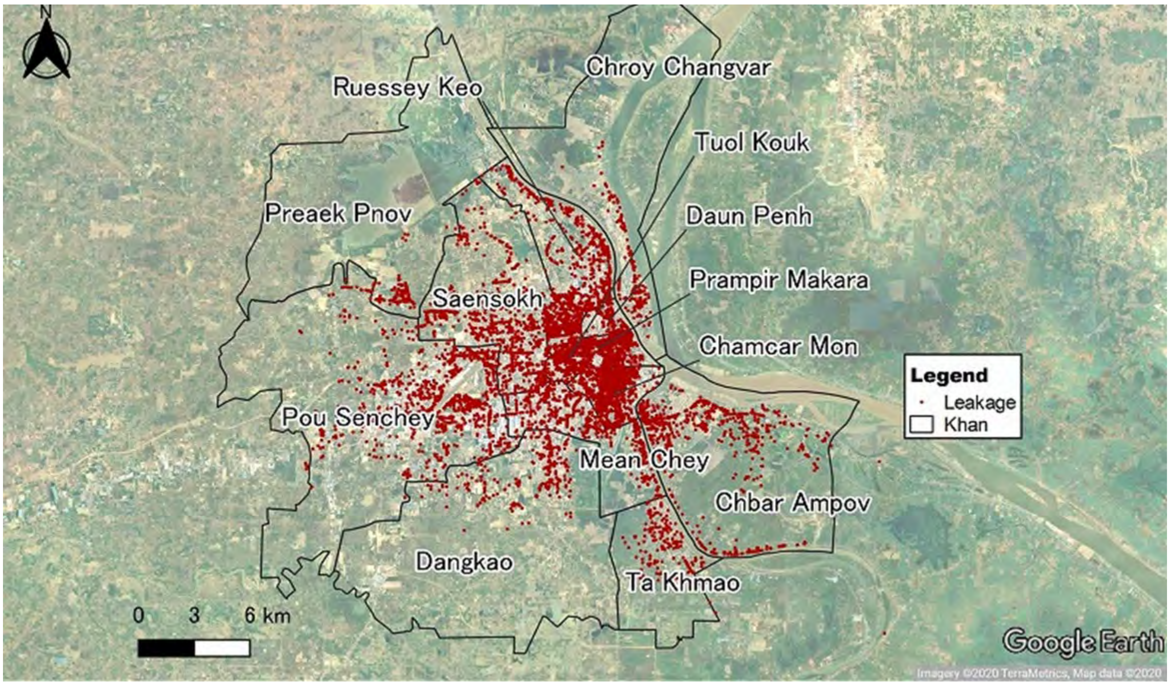


Figure 7.1.18 Summary of Leakage Conditions
Source: JICA Data Collection Survey Team based on PPWSA GIS data

Water leakages have been verified throughout Phnom Penh. However, leaks tend to be concentrated in areas known of have old pipes (Khan Daun Penh, Khan Prampir Makar, Khan Chamcar Mom, Khan Tuol Kouk) and areas that have high water pressure. In addition, as mentioned earlier, PPWSA and private enterprises use different standards. Service areas taken over from private enterprises (Khan Chbar Ampov) also tend to have higher leakage rates. Leakages are repaired by PPWSA as a part of their O&M works.

(4) Annual Maintenance Plan

Repair and replacement of distribution lines, flushing from terminus of distribution network, and repair and replacement and pressure regulators, air valves, and fire hydrants are performed as part of the annual maintenance activities. They are summarized in ***Table 7.1.10***.

Table 7.1.10 Outline of Annual Maintenance Plan

MAINTENANCE ITEMS	ANNUAL PLANNED QUANTITIES
Clean, prepare and modify main pipe	350 places
Stop valve and valve box repair	320 places
Air valve and air valve box repair	80 places
Fire hydrant repair	60 places
Leaking repair work	2,000 places
Water meter repair	20,000 places

Source: JICA Data Collection Survey Team based on hearing to PPWSA

7.1.4 Private Water Supply Facilities

Water is supplied by private enterprises in several locations throughout Phnom Penh and in neighbouring Kandal Province. Areas supplied by private operators are shown in ***Figure 7.1.19***. Their relations to large-scale development projects users discussed in ***Chapter 4*** are summarized in ***Table 7.1.11***.

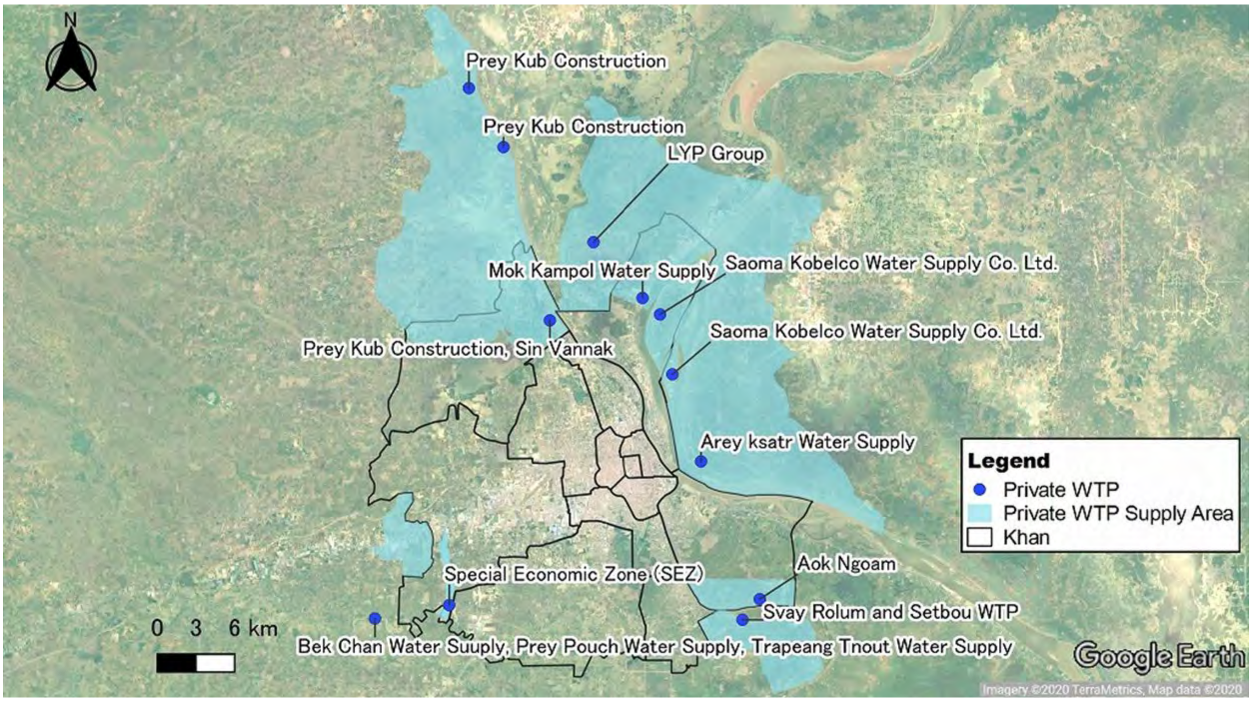


Figure 7.1.19 Summary of Private Water Supply Facilities
Source: JICA Data Collection Survey Team based on PPWSA GIS data

Table 7.1.11 Relation of Large-Scale Development Projects and Private Water Supply Facilities

Large-Scale Development Plans Area		**Private Company Name/ Registered Name**	**Production Capacity of WTP**
Group 2-1	Special Economic Zone (SEZ)	Special Economic Zone (SEZ)	12,500 m^3/day
Group 2-3	private utilities	LYP Group	1,000 m^3/day
Group 2-4	Prek Pnov (private)	Prey Kub Construction, Sin Vannak	3,000 m^3/day
Group 2-5	Bek Chan (private)	Bek Chan Water Suuply, Prey Pouch Water Supply, Trapeang Tnout Water Supply	3,000 m^3/day, 1,400 m^3/day, 700 m^3/day
Group 2-6	North of Chroy Changvar	Mok Kampol Water Supply	3,200 m^3/day
Group 2-7	private utilities	Aok Ngoam	4,000 m^3/day
Group 2-8	private utilities	Svay Rolum and Setbou WTP	1,000 m^3/day
Group 2-9		Prey Kub Construction	3,000 m^3/day
Group 3-1, 3-2	Arey Khsat & Leva Aem commune (private)	Arey ksatr Water Supply	2,000 m^3/day
-		SAOMA Kobelco Water Supply Co. Ltd.	1,800 m^3/day

Source: JICA Data Collection Survey Team

As administrative districts of Phnom Penh change and expand, PPWSA’s service area is also expected to expand. In so doing, it is possible that PPWSA will take over water supply operations from private enterprises.

7.2 PROPOSED TRANSMISSION AND DISTRIBUTION NETWORK EXPANSION PROGRAM

7.2.1 Transmission Network Expansion Program

(1) Water Supply Area

PPWSA's 2030 water supply area is shown in ***Figure 7.2.1***.

The supply area will be the capital Phnom Penh and Ta Khmao City in Kandal Province to the south.

In preparation for 2030, the PPWSA service area has been expanding steadily and will include the entire administrative area of Phnom Penh by 2030. Large-scale development projects within the city and expansion of the city itself will also be included.

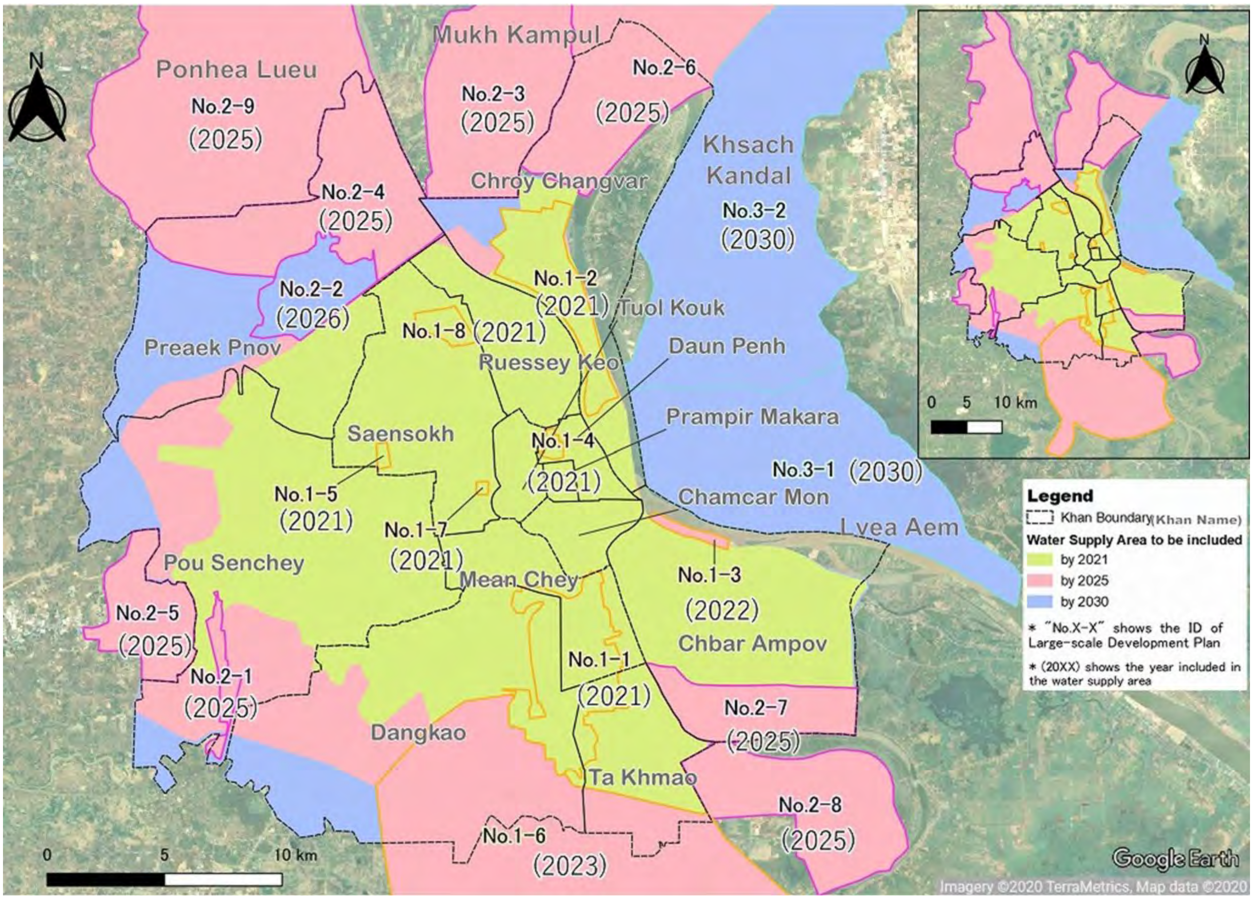


Figure 7.2.1 Summary of Water Supply Area
Source: JICA Data Collection Survey Team

Table 7.2.1 Major Development Projects in the Supply Area and Surrounding Areas

Group	Description	No	Name	Target Supply Year
Group 1	Large-scale development plans which have been already started or which will be started soon.	1-1	ING City	2021
		1-2	OCIC & Okide Villa	2021
		1-3	Kos Norea Project	2022
		1-4	Boeng Kak	2021
		1-5	Okide Villa	2021
		1-6	New Phnom Penh Airport City	2023
		1-7	Booyoung Town	2021
		1-8	Grand Phnom Penh international City	2021
Group 2	West side of Mekong River	2-1	Special Economic Zone (SEZ)	2025
	Large-scale development plans / Areas	2-2	Ta Mouk Lake	2026
	currently supplied by private utilities	2-3	private utilities	2025

Group	Description	No	Name	Target Supply Year
	There are uncertainties whether the project would be carried out or not. Supplied by private sector continuously or supplied by PPWSA	2-4	Prek Pnov (private)	2025
		2-5	Bek Chan (private)	2025
		2-6	North of Chroy Changvar	2025
		2-7	private utilities	2025
		2-8	private utilities	2025
		2-9	Preaek Ta Teaen, Vihear Luong, Ponhea Lueu, Phsar Daek, Kampong Luong, Chhveang, Phnum Bat, Chrey Loas	2025
Group 3	Ditto (East side of Mekong River and North side)	3-1	Arey Khsat & Leva Aem commune (private)	2030
		3-2	Preaek Luong, Preaek Takov, Svay Chrum, Preaek Ta Mak, Preaek Ampil, Puk Russei	2030

Source: JICA Data Collection Survey Team

(2) Future Demand

Water demand and demand distribution of the current survey, which includes the large-scale development projects discussed in ***Chapter 4***, and that reported in the Third Master Plan (M/P2017) are compared in ***Figure 7.2.2***.

Khan	Demand Forecast from Third M/P (M/P 2017) (m^3/day)	Demand forecast of current survey (m^3/day)
Daun Penh	61,308	61,351
Prampir Makara	24,008	32,442
Chamcar Mon	69,060	118,192
Tuol Kouk	51,074	73,776
Ruessey Keo	97,004	109,127
Mean Chey	119,429	132,478
Dangkao	108,336	107,236
Pou Senchey	245,557	338,835
Saensokh	145,683	160,953
Chroy Changvar	55,861	85,862
Chbar Ampov	64,139	99,880
Preaek Pnov	23,520	26,117
Ta Khmao	28,068	56,291

Source: JICA Data Collection Survey Team

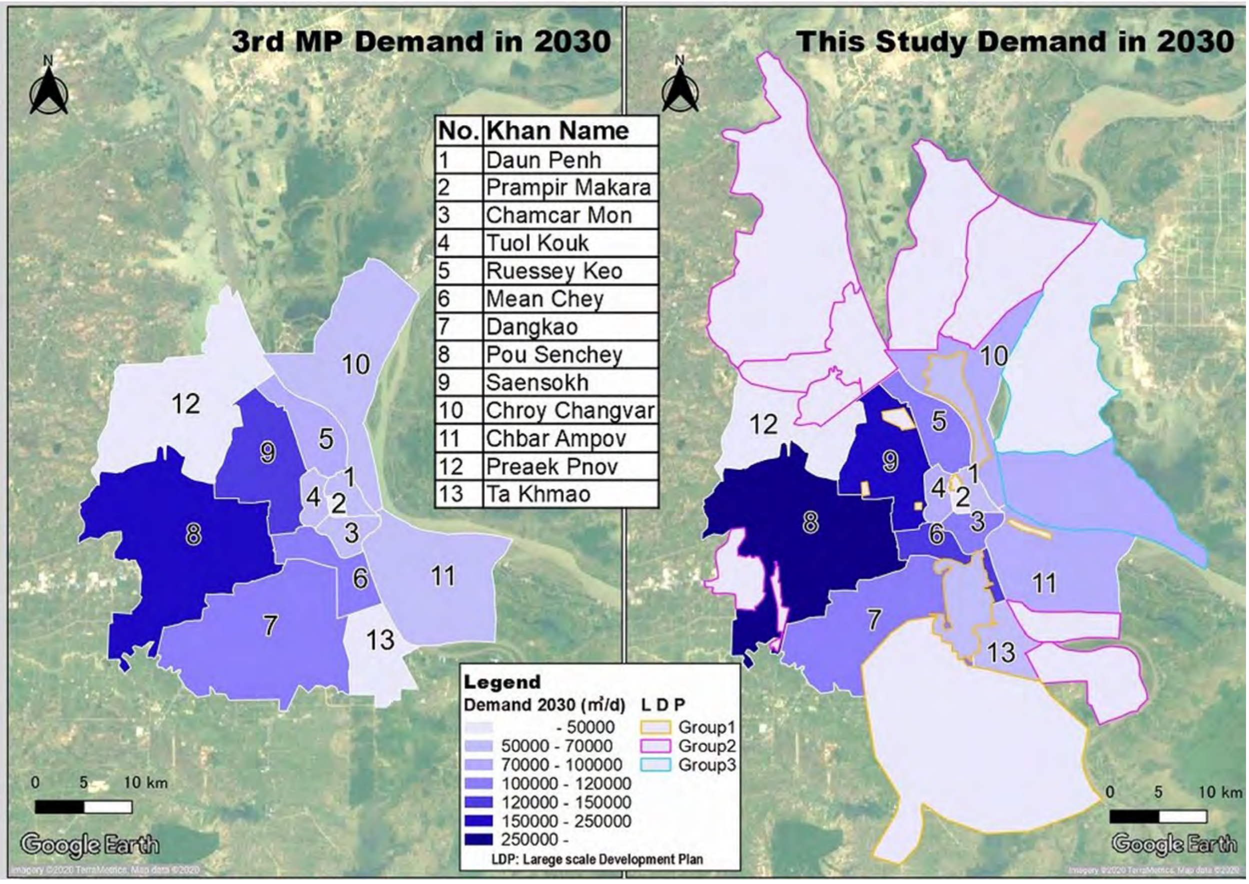


Figure 7.2.2 Comparision of 2030 Water Demand Forecast Distribution

Source: JICA Data Collection Survey Team

When compared to the Third Master Plan (M/P2017), water demand in the urban center of Phnom Penh (Khan Chamcar Mon, Khan Tuol Kouk) and the surrounding area (Khan Mean Chey, Khan Saensokh, Khan Pou Senchey) are higher in the current survey. In addition, the water required by the large-scale development projects further increases the water demand in 2030.

(3) Improvement of WTP

Water will be supplied to each DMA from existing and planned WTPs. Locations of the planned WTPs are shown in ***Figure 7.2.3***. Production capacities and pump data are shown in ***Table 7.2.2***.

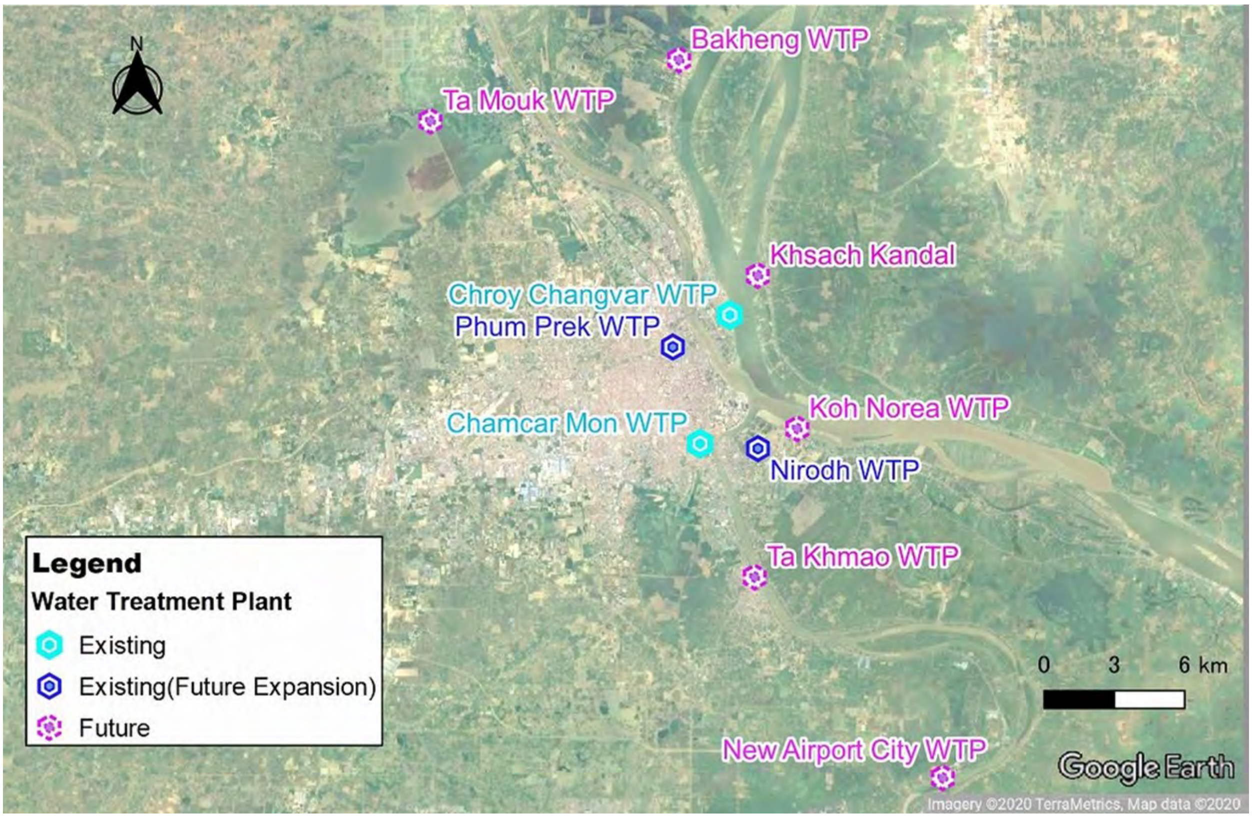


Figure 7.2.3 Summary of WTPs
Source: JICA Data Collection Survey Team

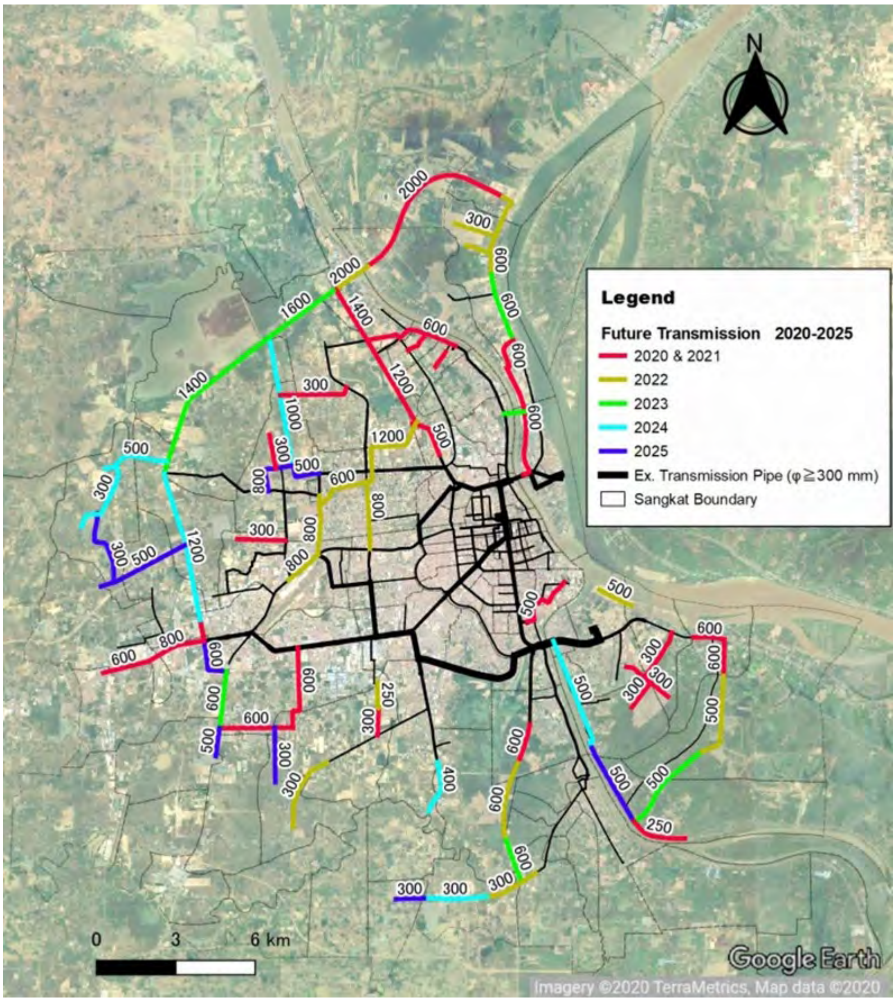
Table 7.2.2 Design Supply Capacity of WTPs

WTP		Production Capacity (m^3/day)	Ground Level (m AMSL)	Planed Pump Head (m)	Total Head (m)
Phum Prek WTP	Existing	150,000	12	42	54
Phum Prek WTP III	Expansion	45,000	12	42	54
Chamcar Mon WTP	Existing	52,000	10	46	56
Chroy Changvar WTP	Existing	130,000	11	46	57
Nirodh WTP I	Existing	130,000	13	57	70
Nirodh WTP II	Existing	130,000	13	57	70
Nirodh WTP III	Expansion	130,000	13	61	74
Bakheng WTP I	New	195,000	10	63	73
Bakheng WTP II	Expansion	195,000	10	63	73
Bakheng WTP III	Expansion	195,000	10	63	73
Ta Khmao WTP	New	30,000	12	45	57
Koh Norea WTP	New	150,000	10	62	72
Ta Mouk WTP I	New	200,000	9	58	67
Ta Mouk WTP II	Expansion	200,000	9	58	67
Khsach Kandal WTP	New	100,000	11	45	56
New Airport City WTP	New	30,000	9	45	54

Source: JICA Data Collection Survey Team

(4) Annual Installation Plan by PPWSA

PPWSA is creating a transmission main development plan based on the Chamkar Mon Phase II Project and Bakheng Phase I and Phase II Projects. The transmission main development plan is outlined in ***Figure 7.2.4***.



Year	Diameter	Length (m)
2020	250mm to 800mm	25,500
2021	300mm to 2000mm	31,500
2022	250mm to 2000mm	33,400
2023	500mm to 1600mm	20,700
2024	300mm to 1200mm	24,700
2025	300mm to 800mm	19,200
Total		155,000

Figure 7.2.4 Transmission Network Installation Plan by PPWSA
Source: JICA Data Collection Survey Team based on PPWSA annual plan

(5) Transmission Line Development Plan

1) Transmission Line Development Policy

(a) Development Policy

The transmission line expansion plan will use pump pressure from each WTP to supply adequate pressure and volume in 2030. In addition, expansion will correspond with the WTP expansion described in Chapter 8. The transmission line expansion plan and policy are outlined in ***Figure 7.2.5*** and ***Table 7.2.3***.

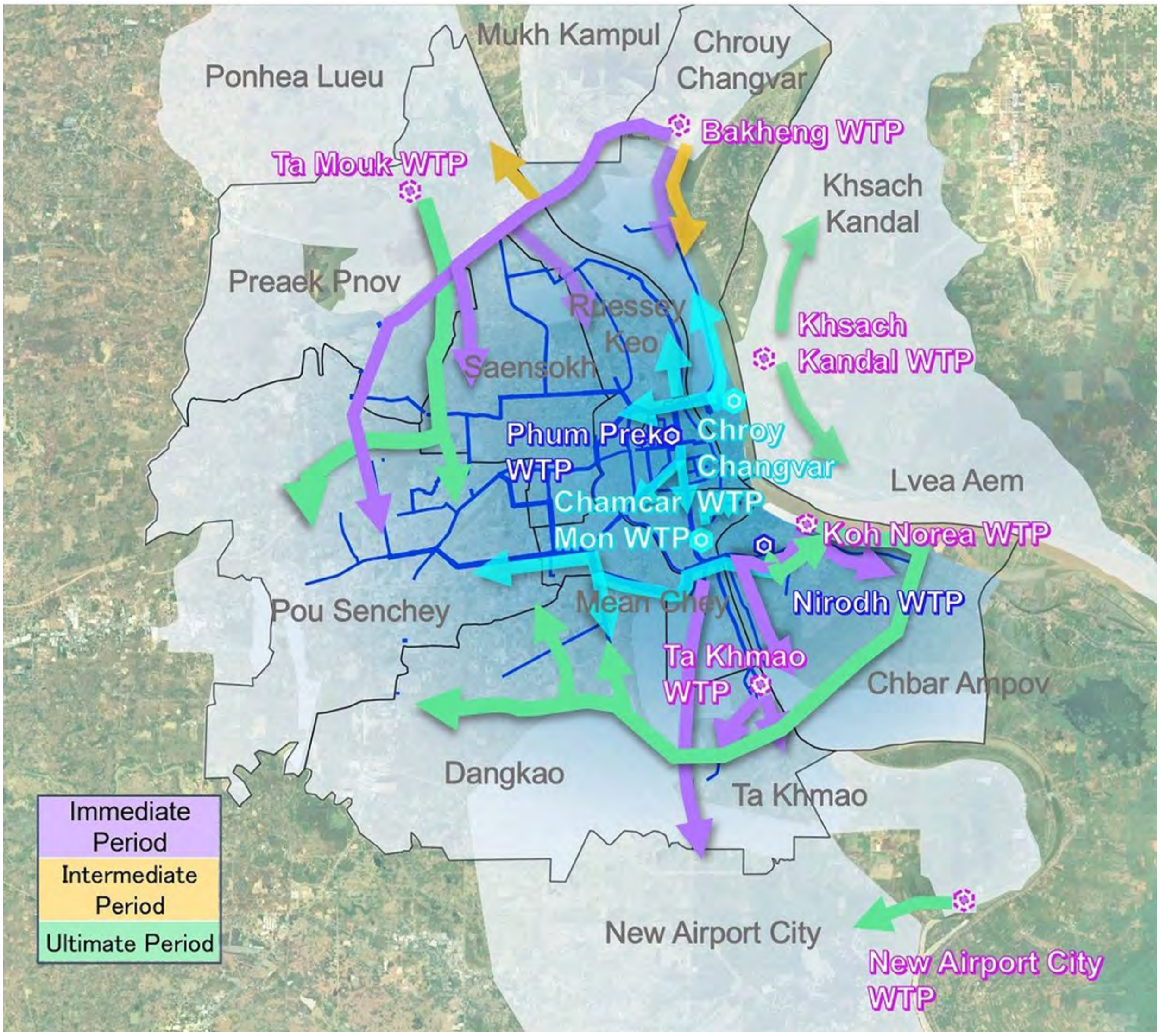


Figure 7.2.5 Summary of Transmission Plan
Source: JICA Data Collection Survey Team

Table 7.2.3 Summary of Development Policy of Transmisison Lines

Stage	Summary of Stage Plan
IMMEDIATE PERIOD	Implement the Bakheng Phase I and II Projects as planned in the Third Master Plan (M/P 2017) and pump water from the five WTPs. The WTPs will be interconnected, and water will be supplied through pump pressure. Independent distribution areas will not be established. After the completion of the Ta Khmao WTP, Ta Khmao City will be established as an independent water supply area. The New Airport City will receive water from the Nirodh WTP extending the existing water lines.
INTERMEDIATE PERIOD	Phum Prek Phase III will accommodate the new demand in the city center (Khan Daun Penh, Khan Prampir Makara, Khan Chamcar Mon, Khan Tuol Kouk). Bakheng Phase III will be interconnected to the system and help secure supply volume and pressure required by the new demand in the central and northern areas (Khan Ruessey Keo,

Stage	Summary of Stage Plan
	Khan Saensokh, Khan Chroy Changvar) and western areas (Khan Pou Senchey). The New Airport City will receive water from the Nirodh WTP extending the existing water lines.
ULTIMATE PERIOD	Nirodh Phase III will supply water to the city center and area near the airport (Khan Mean Chey). Ta Mouk WTP will supply water to the western area (Khan Preaek Pnov, Khan Pou Senchey). Koh Norea WTP will supply water to the west (Khan Dangkao). All will be interconnected. Khsach Kandal WTP will accommodate demand of the development projects on the east side of the Mekong River (District Lvea Aem District Khsach Kandal). When the New Airport City WTP is completed, supply lines will be switched so that the New Airport City area becomes an independent supply area that is supplied by the New Airport City WTP.

Source: JICA Data Collection Survey Team

The development policy of the Third Master Plan (M/P2017) and that of the current survey are compared in ***Table 7.2.4***. The development policy of this survey is to expand the transmission network to satisfy new demand while integrating the results of the Third Master Plan (M/P2017).

Table 7.2.4 Comparison of Development Policies

Item	Summary of the Development Plan of the Third Master Plan (M/P2017)	Summary of the Development Plan of the Current Survey
Supply area and pressure of each WTP	**(Phase I)** Water will be supplied from the existing four WTPs and distributed by pipe pressure. The network will be interconnected and independent supply zones will not be established. **(Phase II)** After the completion of the Ta Khmao WTP, Ta Khmao City will be established as an independent water supply area. The capital Phnom Penh will continue being supplied by an interconnected network as in Phase I. **(Phase III)** After completion of the Bakheng WTP the transmission pipe will be looped and water will be supplied from each WTP. Independent supply areas for each WTP will not be created.	**[IMMEDIATE PERIOD]** Implement the Bakheng Phase I and II Projects as planned in the Third Master Plan (M/P 2017) and pump water from the five WTPs. The WTPs will be interconnected and water will be supplied through pump pressure. Independent distribution areas will not be established. After the completion of the Ta Khmao WTP, Ta Khmao City will be established as an independent water supply area. **[INTERMEDIATE PERIOD]** With the completion of Bakheng Phase III, supply water to the city center and the western area. Use interconnected network to secure water pressure. **[ULTIMATE PERIOD]** Nirodh Phase III will supply water to the city center and area near the airport. Ta Mouk WTP will supply water to the western area. Koh Norea WTP will supply water to the west. All will be interconnected. Khsach Kandal WTP will accommodate demand of the development projects on the east side of the Mekong River.
Looping of transmission lines	In the current water supply system, treated water is sent from the south and east to the north and west. After its completion, the Bakheng WTP will send water from the north to the south. It will be connected to the existing system by creating a looped transmission main.	Transmission lines from Bakheng, Ta Mouk, Koh Norea and Nirodh will be connected and looped.
Supply zones	Supply zones will be managed by establishing DMAs and transmission lines will be designed with DMAs in mind.	Supply zones will be managed by establishing DMAs and transmission lines will be designed with DMAs in mind.

Source: JICA Data Collection Survey Team

(b) Factors for planning

Factors for planning the transmission network are described in ***Table 7.2.5***. Details are described in the ***Appendix***.

Table 7.2.5 Factors for Planning Transmission Network

Items	Contents
Supply area	Phnom Penh and surrounding large-scale development areas (Kandal Province)
Water demand	1,814,000 m^3/day (2030 water demand, day max)
Peak factor	1.60
Minimum pressure	>3 bar at transmission line terminus
DMA	185 DMAs + 19 large-scale development areas
Hydraulic analysis software	WaterGEMS
Equation	Hazen Williams
Coefficient of velocity (C-value)	Existing pipes older than 20 years: 110, New pipes or pipes not older than 20 years: 130
WTP production capacity	Refer to Table 7-2.2
Pump head	Refer to Table 7-2.2
Pipe material	Diameter ≥ 300 mm: Ductile Iron (PPWSA standard)

Source: JICA Data Collection Survey Team

The plan will be one that satisfies water volume and pressure needs of 2030. Specifically, the network will supply each DMA with at least 3.0 bar pressure at the DMA inlet (***Figure 7.2.6***). Hydraulic analysis and results are shown in the ***Appendix***.

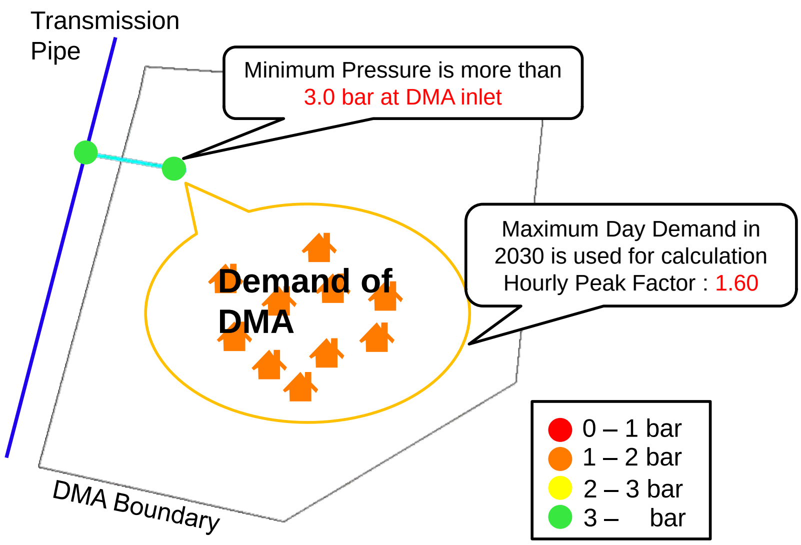
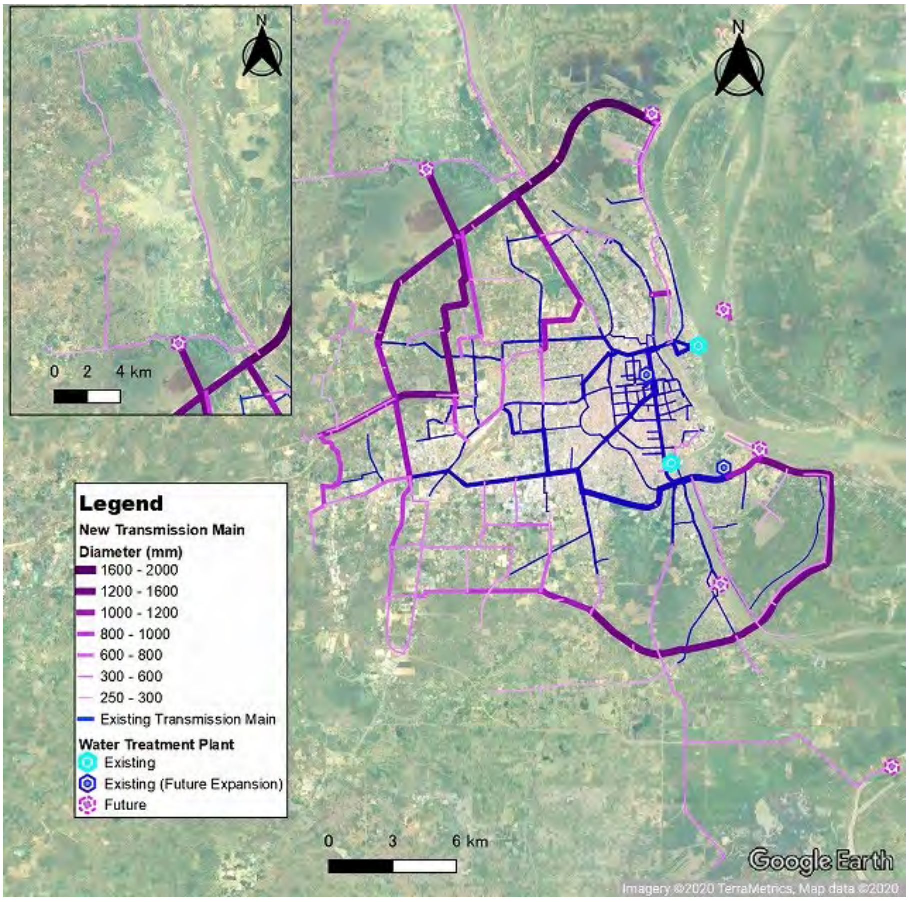


Table 7.2.6 Factors for Planning Water Transmission
Source: JICA Data Collection Survey Team

2) Summary of Transmission Line Development

(a) Improvement Outline

The improvement plan up to the year 2030 is outlined in ***Figure 7.2.7***.



Diameter (mm)	Length (km)
250 mm	6.4
300 mm	61.9
400 mm	30.7
500 mm	63.7
600 mm	62.9
800 mm	20.9
900 mm	1.0
1000 mm	21.2
1200 mm	24.3
1400 mm	18.9
1600 mm	29.3
2000 mm	9.2
Total	350.4

Figure 7.2.6 Summary of Transmission Line Plan until 2030
Source: JICA Data Collection Survey Team

(b) Diameter selection based on efficiency

All transmission network plans propose using pressurized pipes to deliver water from the WTP throughout the network. Pipe diameters were selected with economics and energy efficiency in consideration. In the selection process, initial costs and O&M costs of various diameter pipes were estimated and compared. Table 7.2.1 shows the selection conditions. ***Figure 7.2.7*** shows the results of the comparison.

Table 7.2.1 Conditions for Diameter Selection

Item	Comparison condition
Initial cost	Cost of transmission line, cost of transmission pump
O&M cost	Cost of O&M of pumps (estimated as 7% of the cost of the transmission pumps) Cost of O&M of pipes (estimated as 2% of pipe cost) Cost of electricity for transmission pumps (0.137 USD/kWh)
Replacement cost	Cost of replacing transmission pumps
Others	Lifetime of pipes: 50 years

Source: JICA Data Collection Survey Team

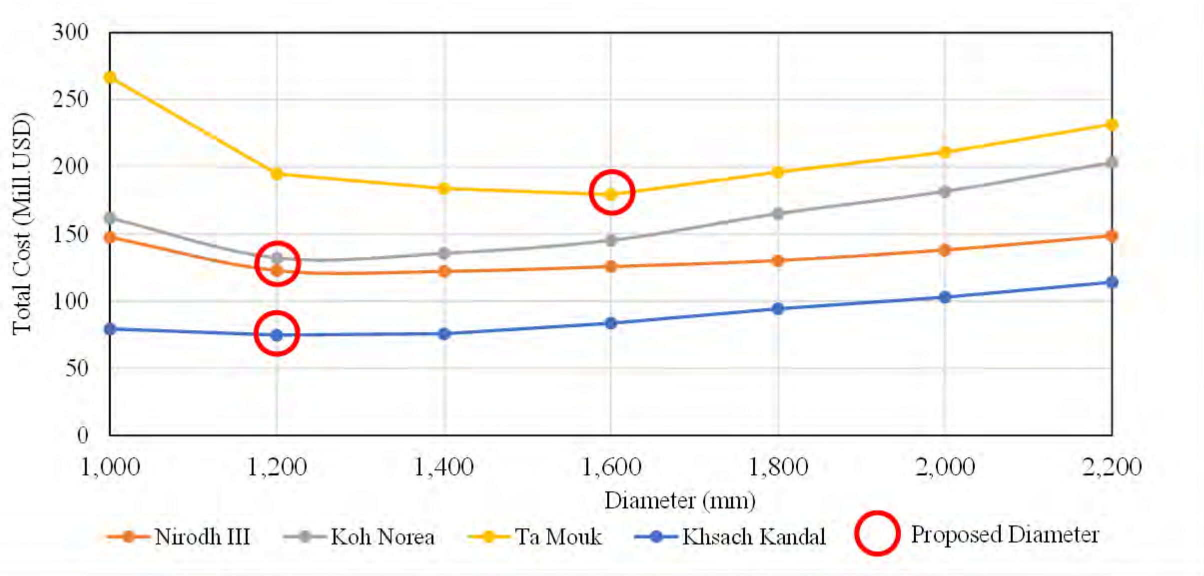


Figure 7.2.7 Results of Pipe Diameter Comparison
Source: JICA Data Collection Survey Team

Selection of larger diameter pipes results in high initial costs. Smaller diameter pipes have lower initial costs but result in higher O&M costs over time since more electric power is needed to overcome frictional losses. The diameters shown in ***Figure 7.2.7*** are those that prioritize energy efficiency.

(c) Particular construction areas

There are several locations in the transmission network that require the transmission line to cross rivers, railways, and roads, and where open-cut method is difficult to use.

a) River crossings

Locations where the transmission line must cross rivers is shown in ***Figure 7.2.8***.

River Crossings

Location

Prek Samrong Bridge (Bassac River Crossing) ①
Proposed DN 1,600 mm L≒500 m (2028)

Prek Thnot River Crossing ②
Proposed DN 1,600 mm L≒50 m (2028)

River Crossings

Koh Norea Waterway Crossing ③
Proposed DN 1,200 mm L≒50 m (2028)

Figure 7.2.8 Locations of River Crossings

Source: JICA Data Collection Survey Team

Possible crossing methods are shown in ***Table 7.2.7***.

Table 7.2.7 River Crossing Methods

	(**Pipe Bridge**)	(**Siphon**)	(**Tunnel**)	(**HDD**)
Summary				
Construction requirements	・Large-scale construction that requires pile foundations and temporary switch-over facilities to be built.	・Special vessels and experts are needed for design and construction. ・Piping protection is needed to avoid erosion and damage.	・Special vessels and experts are needed for design and construction. ・Land is needed for tunneling shaft site. ・To withstand the external pressure, a protective outer pipe or segmenting of the main pipe is needed.	・Special vessels and experts are needed for design and construction. ・Land is required for the driving mechanism. ・To withstand the external pressure, a protective outer pipe needed. ・Pipe diameter is limited. Multiple pipes must be driven to accommodate large flows.
	△	△	○	△
O&M requirements	・Maintenance passageway can be added to give easy access to all parts of the bridge for O&M. ・Air release valve can be installed in optimal location	・Cannot be accessed after completion, making O&M difficult.	・Cannot be accessed after completion, making O&M difficult.	・Cannot be accessed after completion, making O&M difficult.
	◎	◦	○	○
Environmental impacts	・Boat traffic must be considered during and after construction. ・May affect river environment.	・Boat traffic must be considered during and after construction. ・May affect river environment.	・Very little impacts to boat traffic and river environment during and after construction.	・Very little impacts to boat traffic and river environment during and after construction.
	△	△	◎	◎
Cost	13,000 USD/m	14,000 USD/m	24,000 USD/m	19,000 USD/m
	◎	◎	◦	○
Evaluation	○	○	◎	△

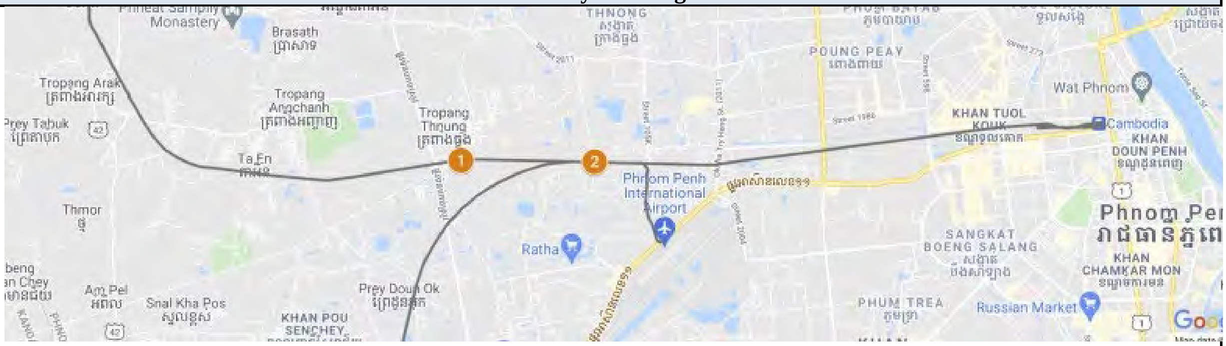
* "Cost" is based on past projects and is not a detailed analysis of costs to be incurred.

Source: JICA Data Collection Survey Team

b) Railway crossings

Locations where the transmission line must cross railway is shown in ***Figure 7.2.9***.

Railway Crossing



Location

Railway Crossing ①
Proposed DN 1,600 mm L≒20m (2030)

Railway Crossing ②
Proposed DN 1,000 mm L≒20m (2030)

Figure 7.2.9 Locations of Railway Crossings

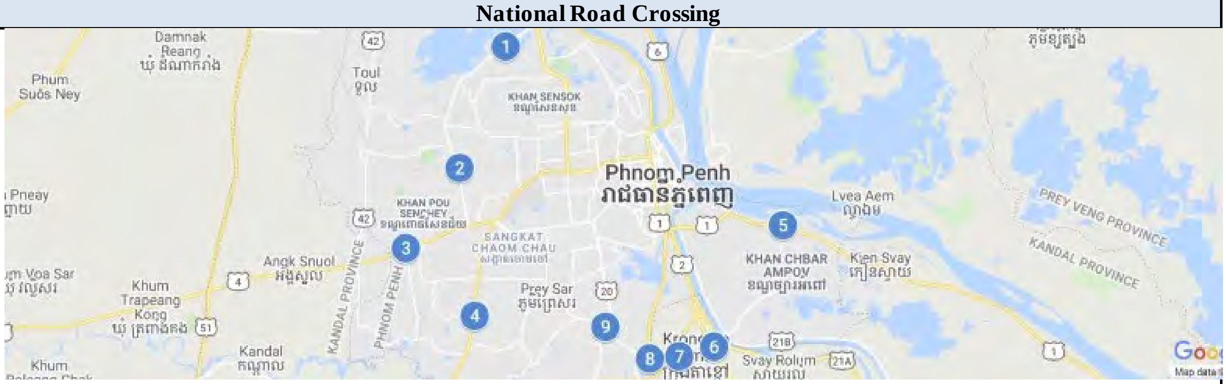
Source: JICA Data Collection Survey Team

Railway crossing works cannot be performed by PPWSA or construction contractors. Crossing works must be outsourced after consultation and coordination with related agencies (MPWT, etc). The tunnelling method is assumed for this survey. Detailed survey of crossing methods and coordination with related agencies will be required in the F/S.

c) Road crossings

Locations where the transmission line must cross the roads is shown in ***Figure 7.2.10***.

National Road Crossing



Location

National Road Crossing

Road Crossing ①
Proposed DN 1,600 mm L≒30m (2030)

Road Crossing ②
Proposed DN 1,200 mm L≒30m (2030)

Road Crossing ③
Proposed DN 1,000 mm L≒30m (2030)

Road Crossing ④
Proposed DN 600 mm L≒30m (2029)

Road Crossing ⑤
Proposed DN 1,600 mm L≒30m (2028)

Road Crossing ⑥
Proposed DN 1,600 mm L≒30m (2028)

Road Crossing ⑦
Proposed DN 1,600 mm L≒30m (2028)

Road Crossing ⑧
Proposed DN 1,600 mm L≒30m (2028)

Road Crossing ⑨
Proposed DN 1,200 mm L≒30 (2028)

Figure 7.2.10 Locations of Road Crossings
Source: JICA Data Collection Survey Team

Many utilities and existing large diameter water supply lines are already buried underground in many places, especially in the urban center of Phnom Penh (Khan Daun Penh, Khan Prampir Makara, Khan Chamcar Mon, Khan Tuol Kouk). Daytime traffic is also very high. In addition, concrete paving work is constantly under way in Phnom Penh and Kandal Province. Therefore, crossing national roads and concrete roads using the open-cut method may be difficult. A non-excavation method (tunnelling method, HDD, etc.) may be required, although these methods are more costly. The tunnelling method is assumed for this survey. Detailed survey of development and road pavement conditions, alternative pipe routes, crossing methods, burial depth, and other factors will need to be discussed with related agencies (MPWT, etc.) in the F/S.

(d) Rearrangement of DMAs

The new DMA arrangement of 2030 based on the development of the transmission network is shown in ***Figure 7.2.11*** and ***Figure 7.2.12***.

Rearrangement of DMAs will be examined based on the water demand projection and transmission network development plan. The coverage areas, pipe lengths, and number of connections of the existing DMAs will be discussed with PPWSA in examining the rearrangement of the DMAs.

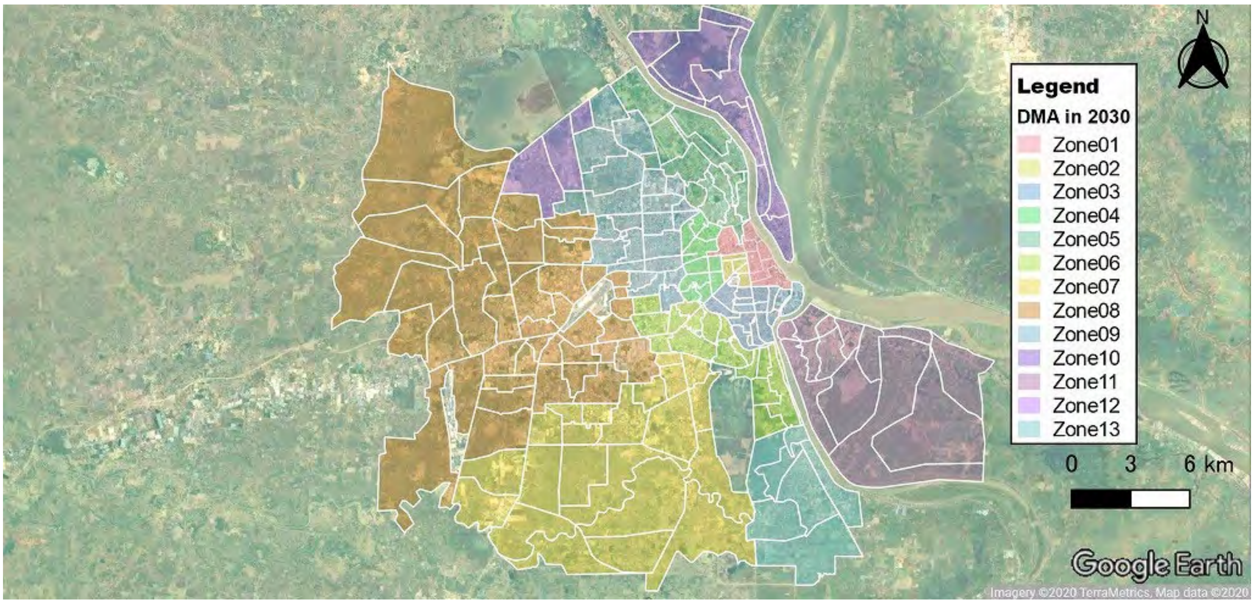


Figure 7.2.11 DMAs in 2030 (1)
Source: JICA Data Collection Survey Team

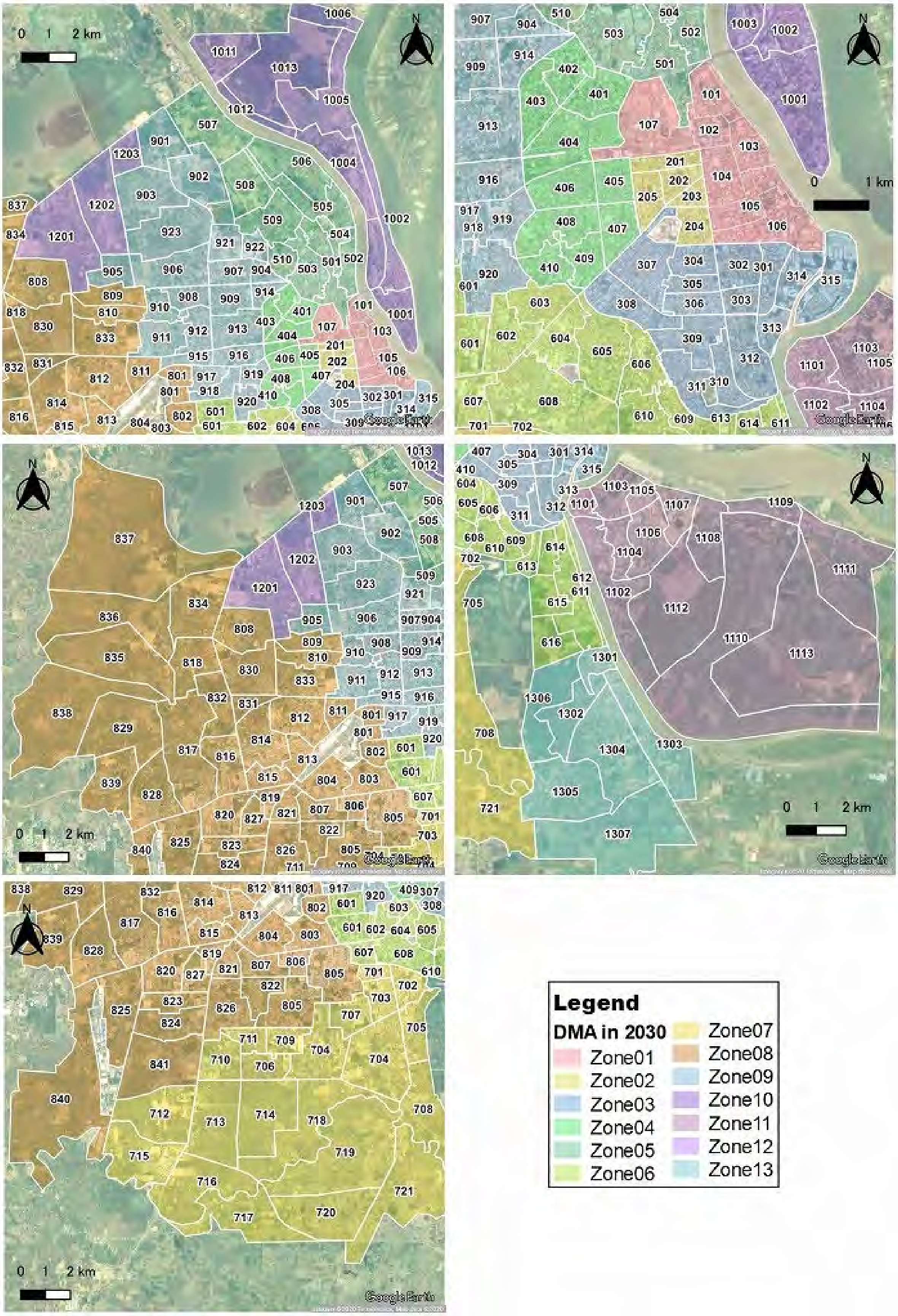


Figure 7.2.12 DMAs in 2030 (2)
Source: JICA Data Collection Survey Team

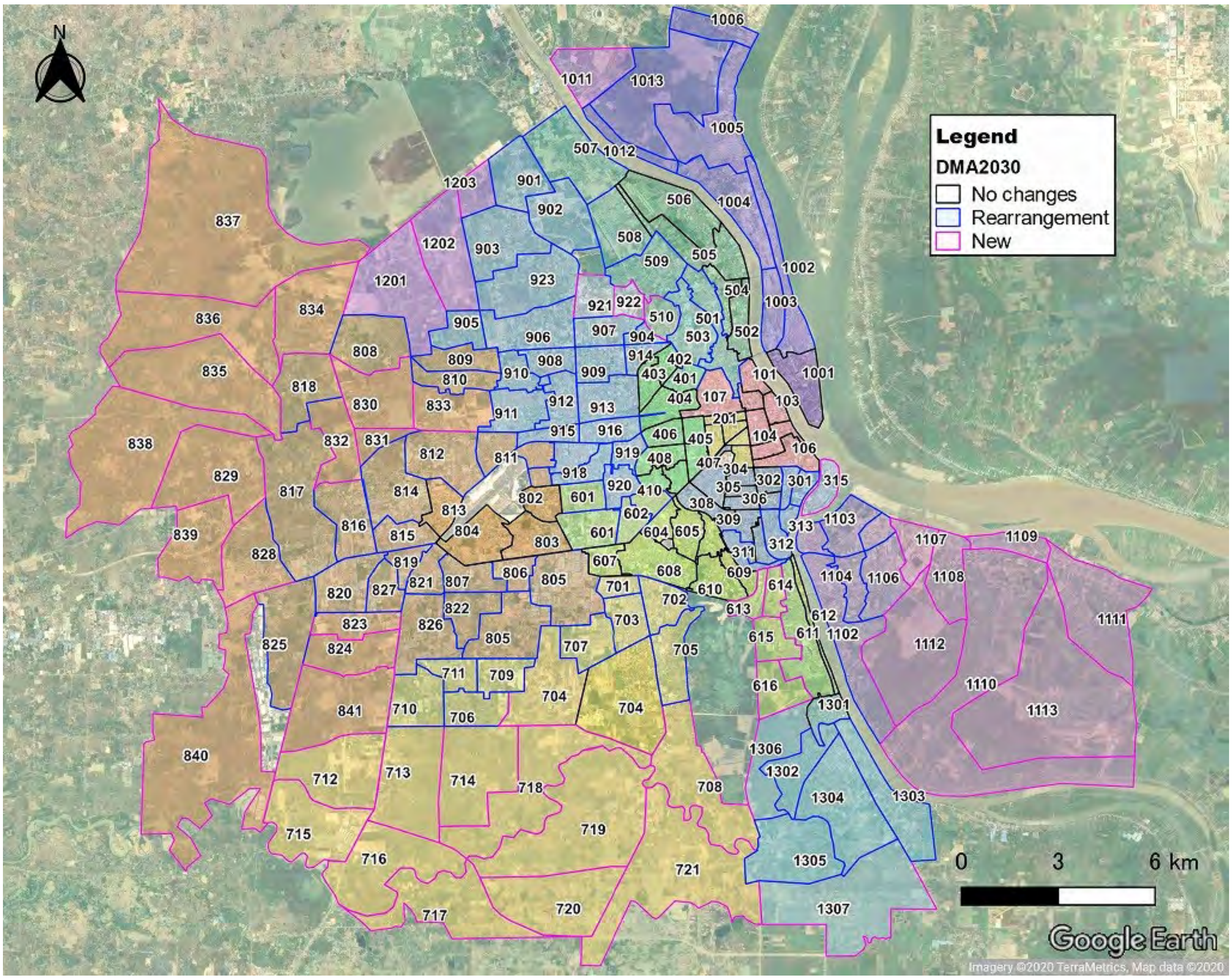


Figure 7.2.13 Summary of DMAs in 2030
Source: JICA Data Collection Survey Team

The rearrangement of the DMAs will be completed by 2025 when the completion of the Bakheng Phase II Project will add water supply areas to western Phnom Penh (Khan Saensokh, Khan Pou Senchey). When other WTPs are completed in 2030, the area north of Phnom Penh (Kan Preaek Pnov) and south of Phnom Penh (Khan Dangkao) will also be arranged in to DMAs (***Figure 7.2.13***). Currently, full DMA operation is not possible due to insufficient water supply. In some areas, boundary valves between DMAs are opened to allow water to flow between DMAs. However, as water production volume increases, appropriate operation of DMAs will become possible.

(e) Pressure distribution

Water pressure distribution of the improved water transmission network in 2030 is shown in ***Figure 7.2.14***.

Water pressure distribution of 2020, 2025, and 2030 are shown and compared in ***Figure 7.2.15***.

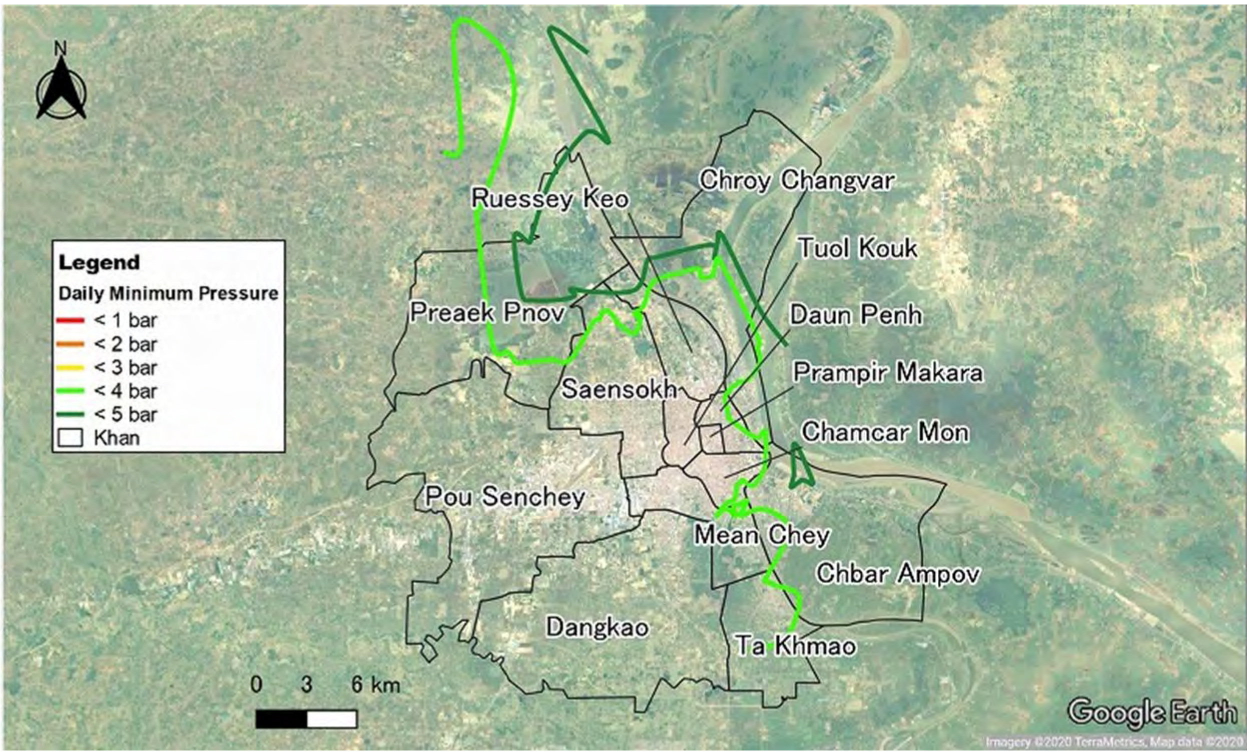


Figure 7.2.14 Water Pressure Distribution in 2030
Source: JICA Data Collection Survey Team

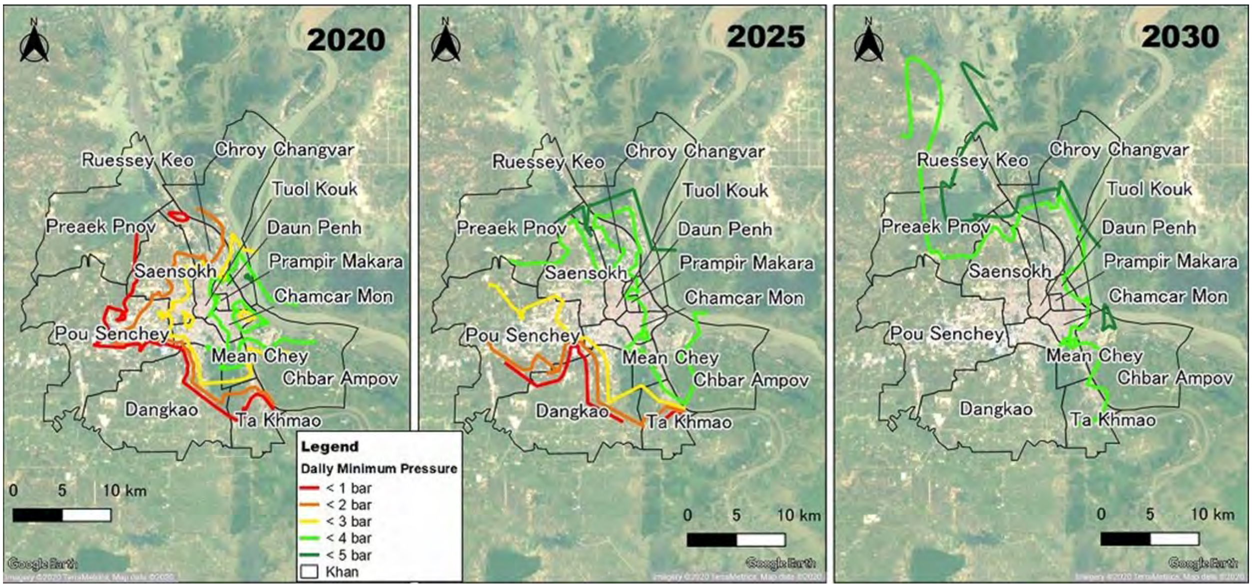


Figure 7.2.15 Comparison of Water Pressures in 2020, 2025, and 2030
Source: JICA Data Collection Survey Team

According to the re-evaluated water demand forecast, it will be difficult to achieve 3 bars of pressure in western (Khan Pou Senchey) and southern (Khan Dangkao) Phnom Penh. The Third Master Plan (M/P2017) also raised concerns about water pressure in western Phnom Penh. By continuing improvement and expansion works beyond 2026, it will be possible to meet the water demand expected in 2030.

(6) Transmission Network Development Plan

1) Transmission Network Development Stages

The transmission network development plan aims to meet water supply needs according to the water demand forecast re-evaluated in this survey. The construction of a transmission network that can accommodate the water demand in 2030 will be costly and take time, and will require staged implementation.

The transmission network will be developed along with the WTPs. Timing of the network improvements are shown in ***Table 7.2.8***.

Table 7.2.8 Staged Development Plan of Transmission Network

Period	Stage (year)	Staged Development Plan of WTP	Staged Development Plan of TM Mains
IMMEDIATE PERIOD	Stage 1 (2021-2023)	Bakheng Phase I (2023) Bakheng Phase II (2023)	Bakheng Phase I TM Bakheng Phase II TM
	Stage 2 (2023-2024)	Ta Khmao (2024)	Ta Khmao TM
INTERMEDIATE PERIOD	Stage 1 (2024-2026)	Phum Prek Phase III (2026)	Phum Prek III TM
	Stage 2 (2026-2027)	Bakheng Phase III (2027)	Bakheng III TM
ULTIMATE PERIOD	Stage 1 (2027-2029)	Nirodh Phase III (2029) Koh Norea (2029) Reconstruction of Phum Prek Phase I (2029)	Koh Norea TM Nirodh III TM
	Stage 2 (2029-2030)	Ta Mouk Phase I (2030) Khsach Kandal (2030) New Airport City (2030) Reconstruction of Phum Prek Phase I (2030)	Ta Mouk TM Khsach Kandal TM New Airport City TM

Source: JICA Data Collection Survey Team

2) Staged Development Plan of Transmission Network

The staged implementation plan is outlined in ***Figure 7.2.16***. Salient details of each phase are shown in ***Table 7.2.9***.

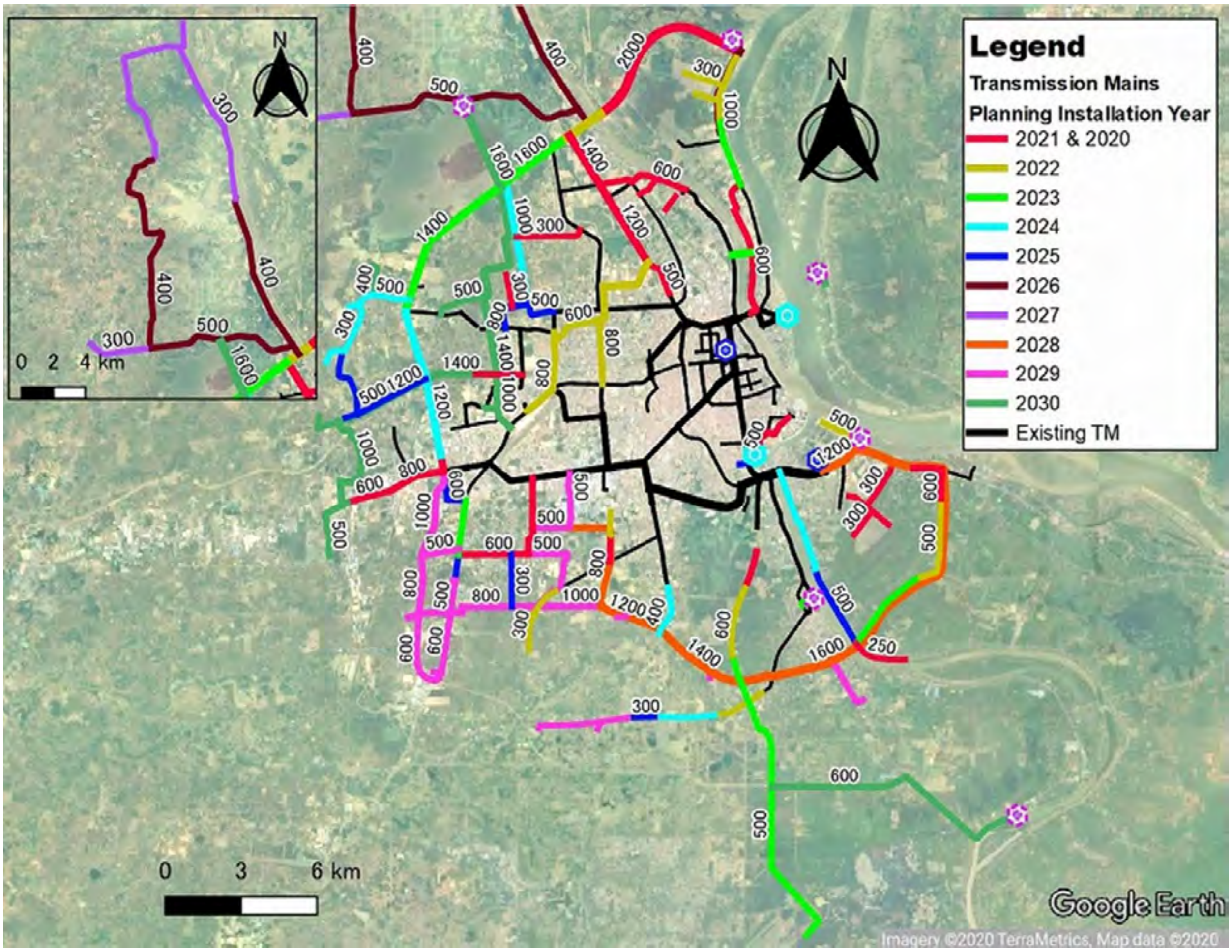


Figure 7.2.16 Summary of Staged Development Plan of Transmission Lines

Source: JICA Data Collection Survey Team

Table 7.2.9 Summary of Staged Development Plan of Transmission Lines

Period	Stage	Project	Component	Diameter (mm)	Length (km)	Implementation Year
IMMEDIATE PERIOD	Stage 1	Bakheng Phase I&II	Transmission Mains	250	5.0	2020-2022
				300	31.0	2020-2025
				400	3.2	2020-2025
				500	26.8	2020-2025
				600	38.6	2020-2023
				800	9.6	2020-2025
				1,000	4.9	2024-2025
				1,200	14.7	2021-2024
				1,400	9.0	2021-2023
				1,600	3.0	2023
				2,000	9.2	2021-2022
	Stage 2	Ta Khmao	Transmission Mains	300	0.01	2023
				500	11.2	2023
				600	0.01	2023
INTERMEDIATE PERIOD	Stage 1	Phum Prek	Transmission Mains	500	0.36	2025
	Stage 2	Bakheng III	Transmission Mains	300	27.1	2027
				400	24.6	2026
				500	9.5	2026
				600	0.8	2026
				1,000	3.6	2026
				1,200	0.3	2026
ULTIMATE PERIOD	Stage 1	Nirodh III	Transmission Mains	250	0.5	2029
				300	3.7	2029
				400	0.6	2029
				500	8.6	2029

Period	Stage	Project	Component	Diameter (mm)	Length (km)	Implementation Year
				600	9.2	2029
				800	9.8	2029
				900	1.0	2029
				1000	5.9	2028
		Koh Norea	Transmission Mains	250	0.9	2029
				300	0.1	2029
				400	0.3	2029
				500	1.0	2029
				600	1.1	2029
				1200	5.2	2028
				1400	3.9	2028
				1600	17.0	2028
	Stage 2	Ta Mouk	Transmission Mains	400	2.0	2030
				500	4.1	2030
				600	1.9	2030
				800	1.6	2030
				1,000	6.3	2030
				1,200	3.8	2030
				1,400	6.0	2030
				1,600	9.4	2030
		Khsach Kandal	Transmission Mains	600	0.2	2030
				1,000	0.5	2030
				1,200	0.2	2030
		New Airport City	Transmission Mains	600	11.0	2030

Source: JICA Data Collection Survey Team

(a) IMMEDIATE PERIOD

The main transmission network development work during the Immediate Period is laying transmission lines to accommodate the Bakheng Phase I, Bakheng Phase II, and Ta Khmao Projects.

In the Bakheng Phase I and Phase II Projects, transmission lines will be laid along the new Ring Road (RR3) to enhance water transmission capacity. However, water demand is expected to exceed that forecast in the Third Master Plan (M/P2017) and there is concern that water pressure to western (Khan Pou Senchey) and southern (Kahn Dangkao) Phnom Penh will remain insufficient.

In addition to laying pipe from Bakheng WTP along RR3, transmission lines will be extended towards central (Khan Saensokh) and western (Khan Pou Senchey) Phnom Penh. The plan is to create a complete loop with the transmission line by the end of the project in order to create a network that is flexible and can accommodate many different situations.

Furthermore, after the completion of the Ta Khmao WTP, water supply conditions will be improved and it will be possible to supply sufficient water to Ta Khmao. In addition, if there is excess water from the Ta Khmao WTP, it can be supplied to Mean Chey in southern Phnom Penh.

(b) INTERMEDIATE PERIOD

Transmission lines will be constructed in the Bakheng Phase III Project to alleviate water pressure and volume issues in western Phnom Penh, the major issue faced in the Immediate Period. The transmission line will be connected to the transmission lines of Bakheng Phase I and Phase II and supply water to western (Khan Pou Senchey) and northern (Khan Saensokh, Khan Chroy Changvar) Phnom Penh.

Also, the completion of Phum Prek Phase III will supply water to central Phnom Penh (Khan Daun Penh, Khan Prampir Makara, Khan Chamcar Mon, Khan Tuol Kouk).

(c) ULTIMATE PERIOD

In order to meet the water demand of western (Khan Pou Senchey) and southern (Khan Dangkao) Phnom Penh, transmission lines laid in the Koh Norea Project and the Ta Mouk Phase I Project to supply water from those WTPs to the target areas while adding flexibility to the transmission network as a whole. In response to the increase in water demand in the central areas (Khan Daun Penh, Khan Prampir Makara, Khan Chamcar Mon, Khan Tuol Kouk), the Nirodh Phase III Project will increase the transmission lines to supply the necessary water.

There are also plans to build a bridge over the Mekong River (the Changvar-Svay Chrum Bridge) to connect Khan Chroy Changvar in Phnom Penh with District Lvea Aem in Kandal Province. The Cambodian Constructors' Association reports that areas on the eastern side of the Mekong River (District Lvea Aem, District Khsach Kandal) will be joined with Phnom Penh after the construction of the bridge, and new developments in these areas are expected. In order to meet the new water demand accompanying the development of the east side of the Mekong River, a transmission line from the newly constructed Khsach Kandal WTP will be laid to secure the required amount of water and water pressure.

3) Future Plans for WTP-Based Distribution Areas to Improve Efficiency

(a) WTP-Based Distribution Areas in 2030

As described in Chapter 8, even if WTPs are constructed according the staged implementation plan, water production capacity will be insufficient to meet all of 2030 demand. In order to ensure sufficient water supply to each area, WTPs must supply water through an interconnected and flexible water supply network. The interconnected system will be monitored and operated through SCADA systems installed in the Bakheng Phase I and Phase II projects and a centralized distribution control room. SCADA monitoring and control will allow for optimal operation of the WTPs and transmission lines.

Regarding the Ta Khmao WTP and Khsach Kandal WTP, the target water supply areas for each WTP are independent and distinct, allowing them to serve specific water supply areas.

Water supply areas of each WTP in 2030 is shown in ***Figure 7.2.17***.

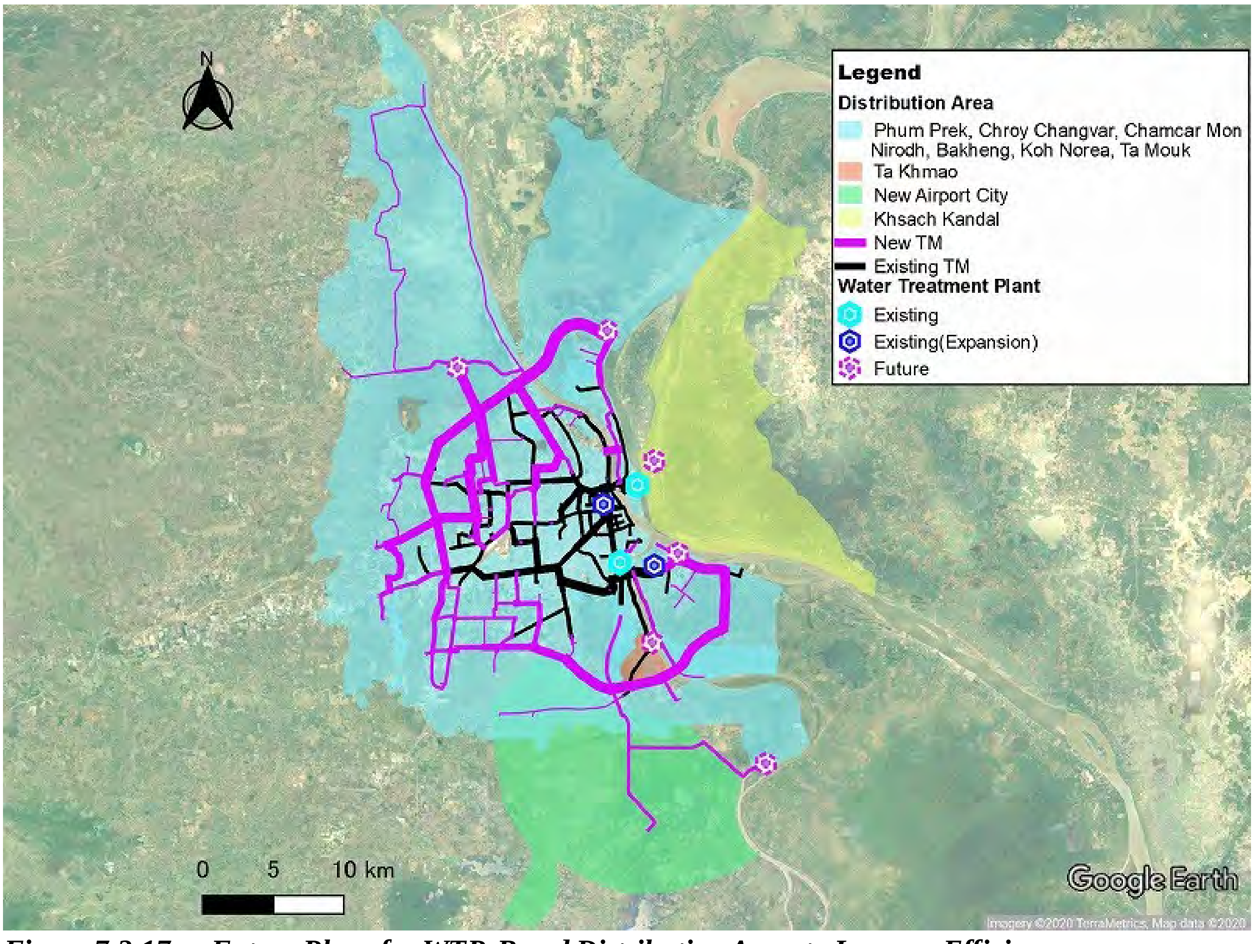


Figure 7.2.17 Future Plans for WTP-Based Distribution Areas to Improve Efficiency
Source: JICA Data Collection Survey Team based

(b) Future Distribution Areas

After 2030, distribution areas for each WTP (Phum Prek WTP, Chamcar Mon WTP, and Chroy Changvar WTP) can be established in central Phnom Penh (Khan Daun Penh, Khan Prampir Makara, Khan Chamcar Mon, and Khan Tuol Kouk), as shown in ***Figure 7.2.18***. However, establishing water distribution areas for each WTP, new boundary valves must be installed to hydraulically isolate the distribution areas. New transmission mains to deliver water to newly created distribution areas may also be needed.

However, water supply will remain tight until 2030 and large-scale development work that causes water shutdowns are not realistic. In central Phnom Penh, it is possible to install boundary valves at the time of pipe renewal and construction planned in Phase I of each WTP development. If distribution areas for each WTP can be established in this way, it will become possible to gain a greater understanding of the water balance and implement more efficient operation.

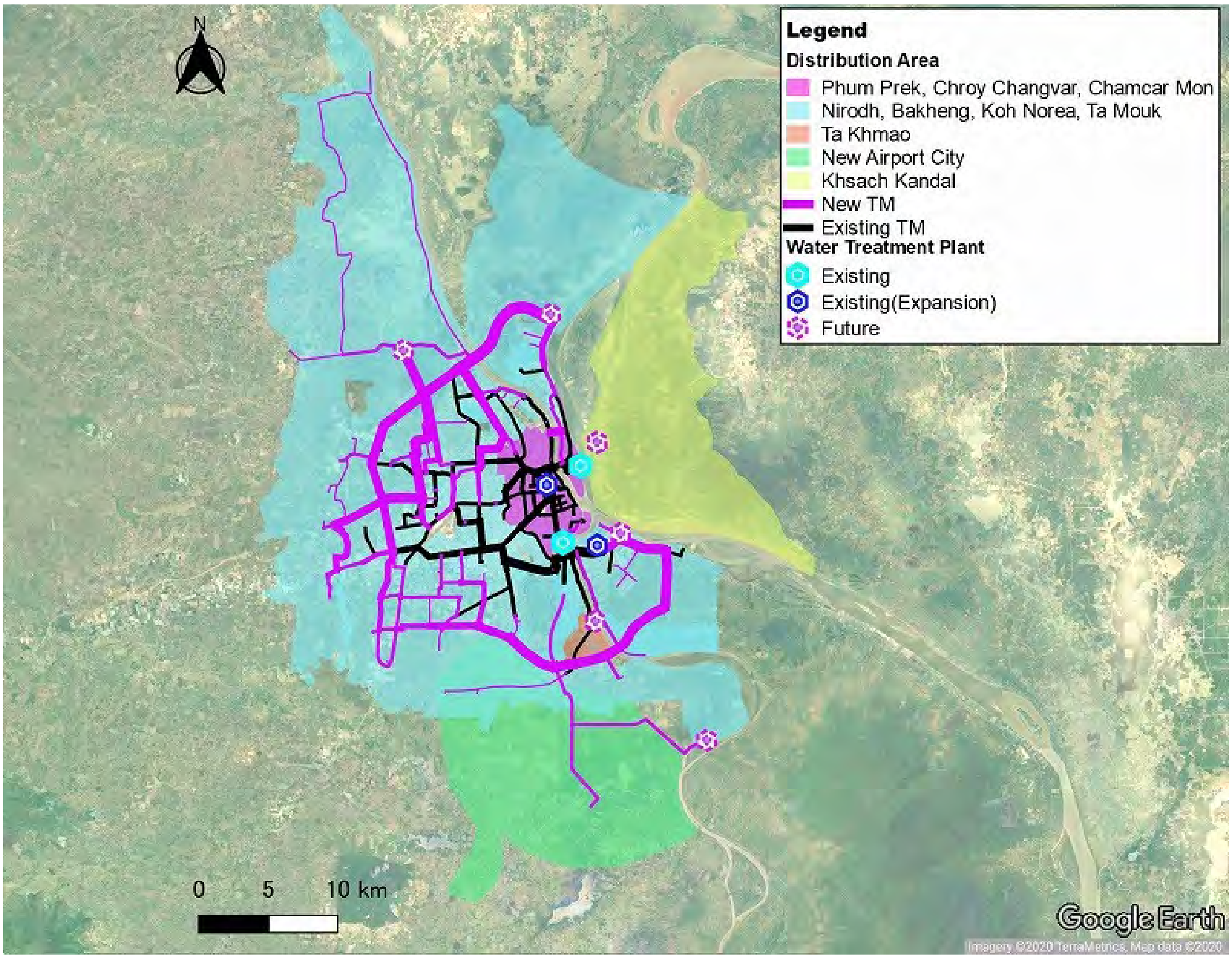


Figure 7.2.18 Distribution Areas of Each WTP

Source: JICA Data Collection Survey Team based

(7) Case Studies of Water Distribution Network Development

In this survey, the water distribution network development plan was proposed based on the water demand forecast for 2030, including large-scale development plans described in Chapter 4. Although the actual 2030 water demand may fluctuate depending on the development conditions of Phnom Penh and the expansion of the water supply area, it is almost certain that the water demand will continue to increase. The main lines of the water distribution network are planned to be developed in consideration of the medium- to long-term water demand. In this section six development scenarios have been considered and analysed as shown in Table 7-2.11. The cases are divided according to water demand and water supply areas. However, there is no major change in the overall development plan for the core system of the water distribution network.

In this section, several cases for the water distribution network development are analysed. Demand of large-scale development projects are not included in the analysis, assuming delays in the implementation of projects. Details of each case are shown in ***Table 7.2.10*** and ***Figure 7.2.19***. In the discussion with PPWSA, these cases are based on the feasibility of each development plan in Phnom Penh.

Table 7.2.10 Supply Area Development Cases

Case	Contents
Case 1	Large-Scale Development Project Group 1 is added to the PPWSA service area
Case 2	Large-Scale Development Project Group 1 and Group 2 are added to the PPWSA service area
Case 3	Large-Scale Development Project Group 1 and Group 3 are added to the PPWSA service area
Case 4	Large-Scale Development Project Group 1 (excluding Project 1-6 New Phnom Penh Airport City) is added to the PPWSA service area
Case 5	Large-Scale Development Project Group 1 and Group 2 (excluding 2-9 Preaek Ta Teaen, Vihear Luong, Ponhea Lueu, Phsar Daek, Kampong Luong, Chhveang, Phnum Bat, Chrey Loas) are added to the PPWSA service area
Case 6	Large-Scale Development Project Group 1, Group 2, and Group 3 are added to the PPWSA service area and Boeng Thom WTP is also constructed

Source: JICA Data Collection Survey Team based

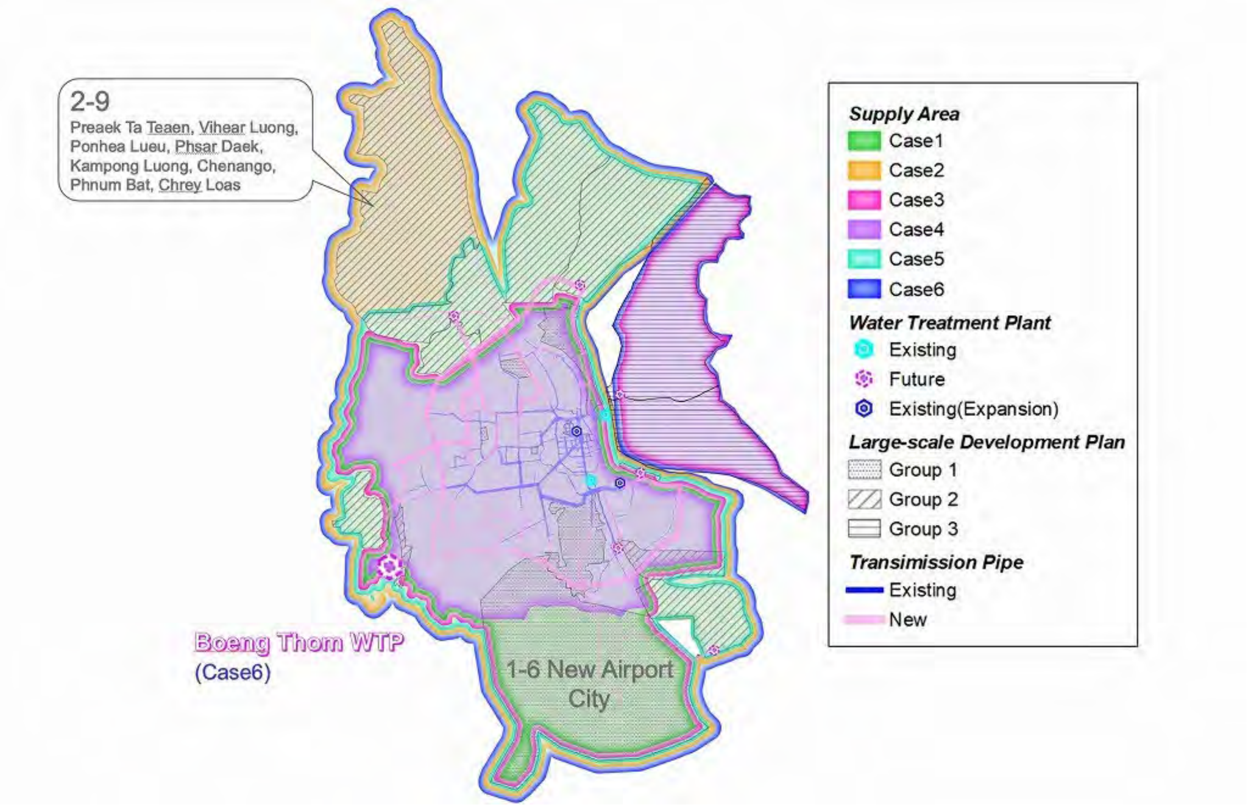


Figure 7.2.19 Cases of Water Supply Area Development
Source: JICA Data Collection Survey Team based

(a) Case 1

Figure 7.2.20 shows details of Case 1: Large-Scale Development Project Group 1 is added to the PPWSA service area.

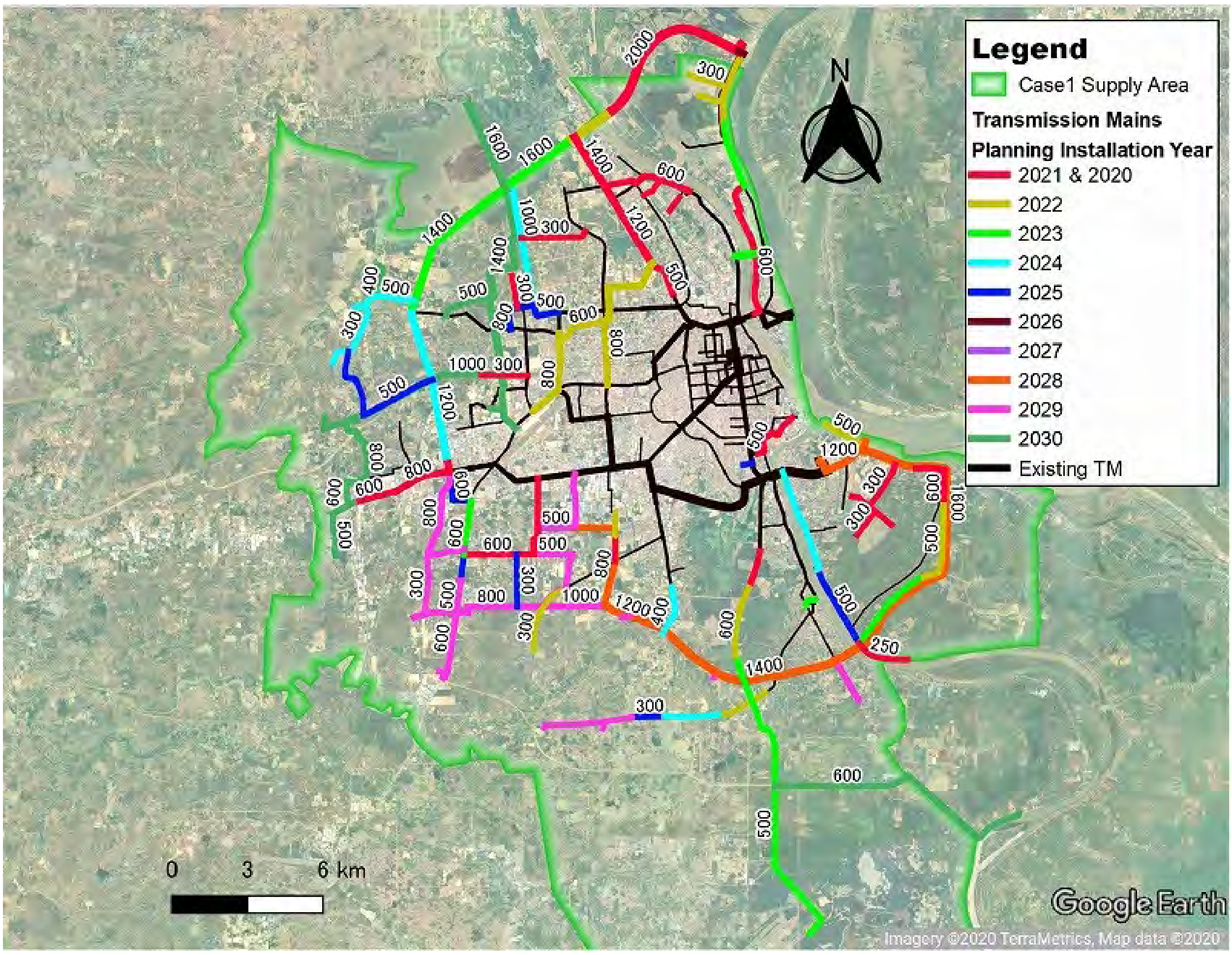


Figure 7.2.20 Water Supply Area Development Plan for Case 1

Source: JICA Data Collection Survey Team based

(b) Case 2

Figure 7.2.21 shows details of Case 2: Large-Scale Development Project Group 1 and Group 2 are added to the PPWSA service area.

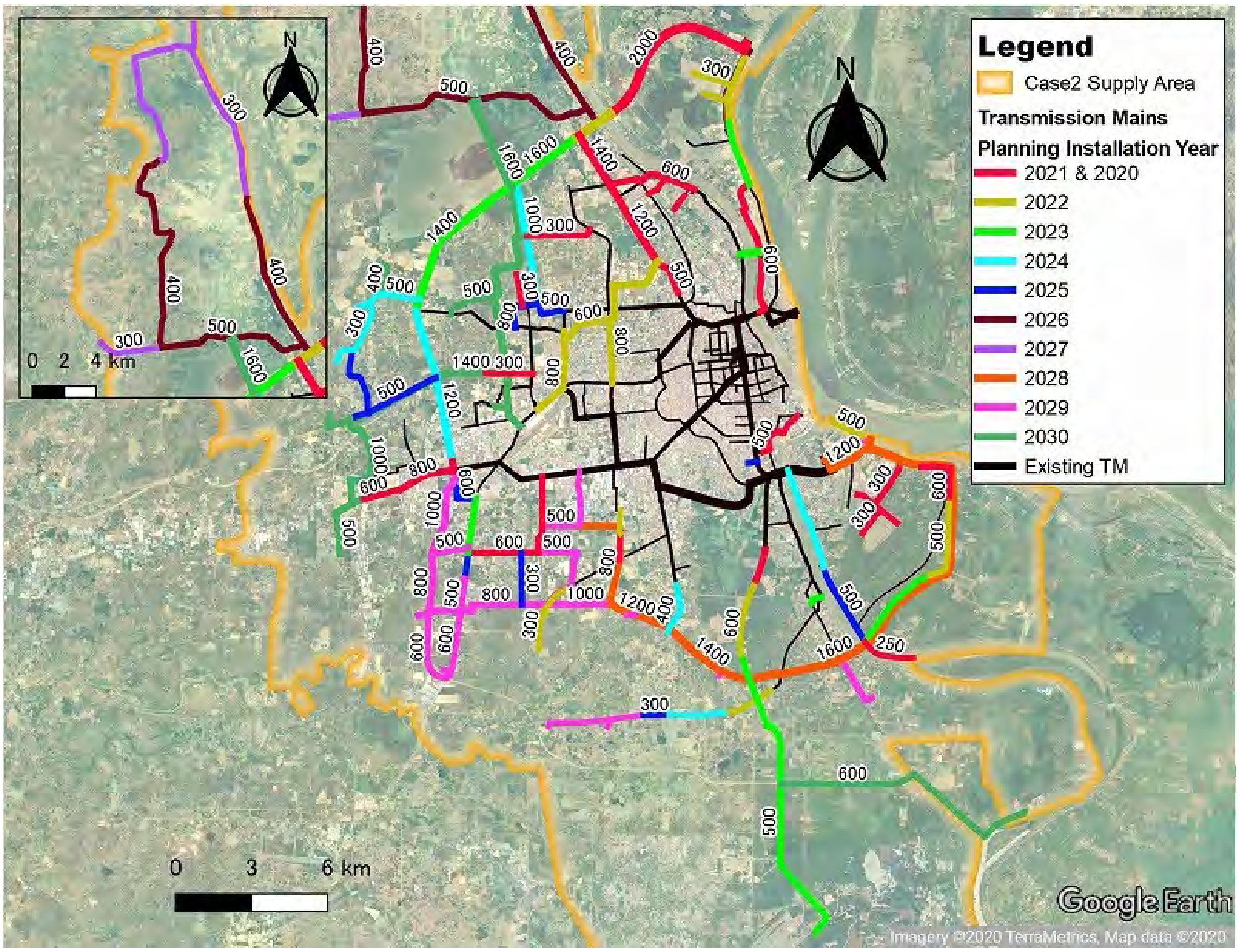


Figure 7.2.21 Water Supply Area Development Plan for Case 2
Source: JICA Data Collection Survey Team based

(c) Case 3

Figure 7.2.22 shows details of Case 3: Large-Scale Development Project Group 1 and Group 3 are added to the PPWSA service area.

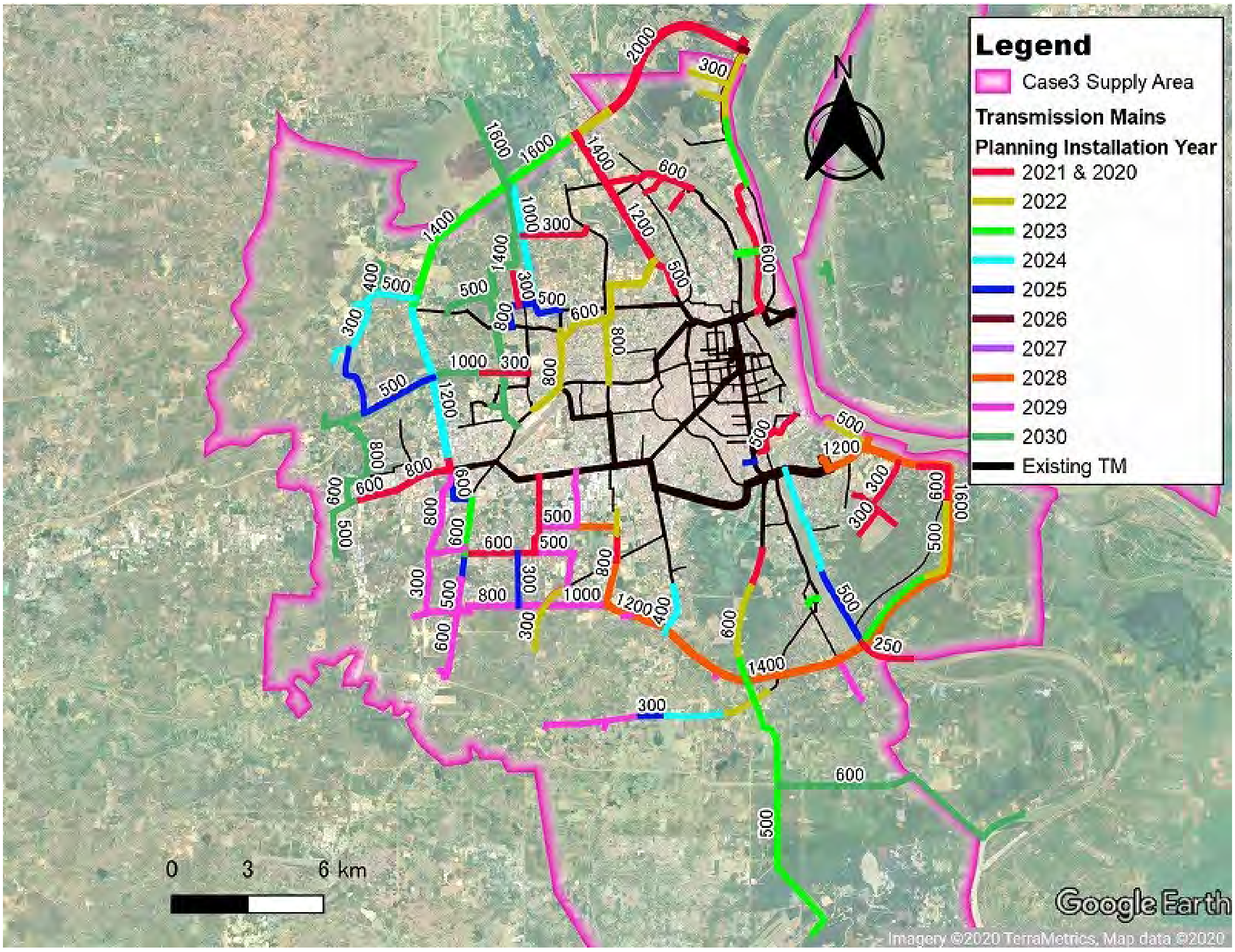


Figure 7.2.22 Water Supply Area Development Plan for Case 3
Source: JICA Data Collection Survey Team based

(d) Case 4

Figure 7.2.23 shows details of Case 4: Large-Scale Development Project Group 1 (excluding Project 1-6 New Phnom Penh Airport City) is added to the PPWSA service area.

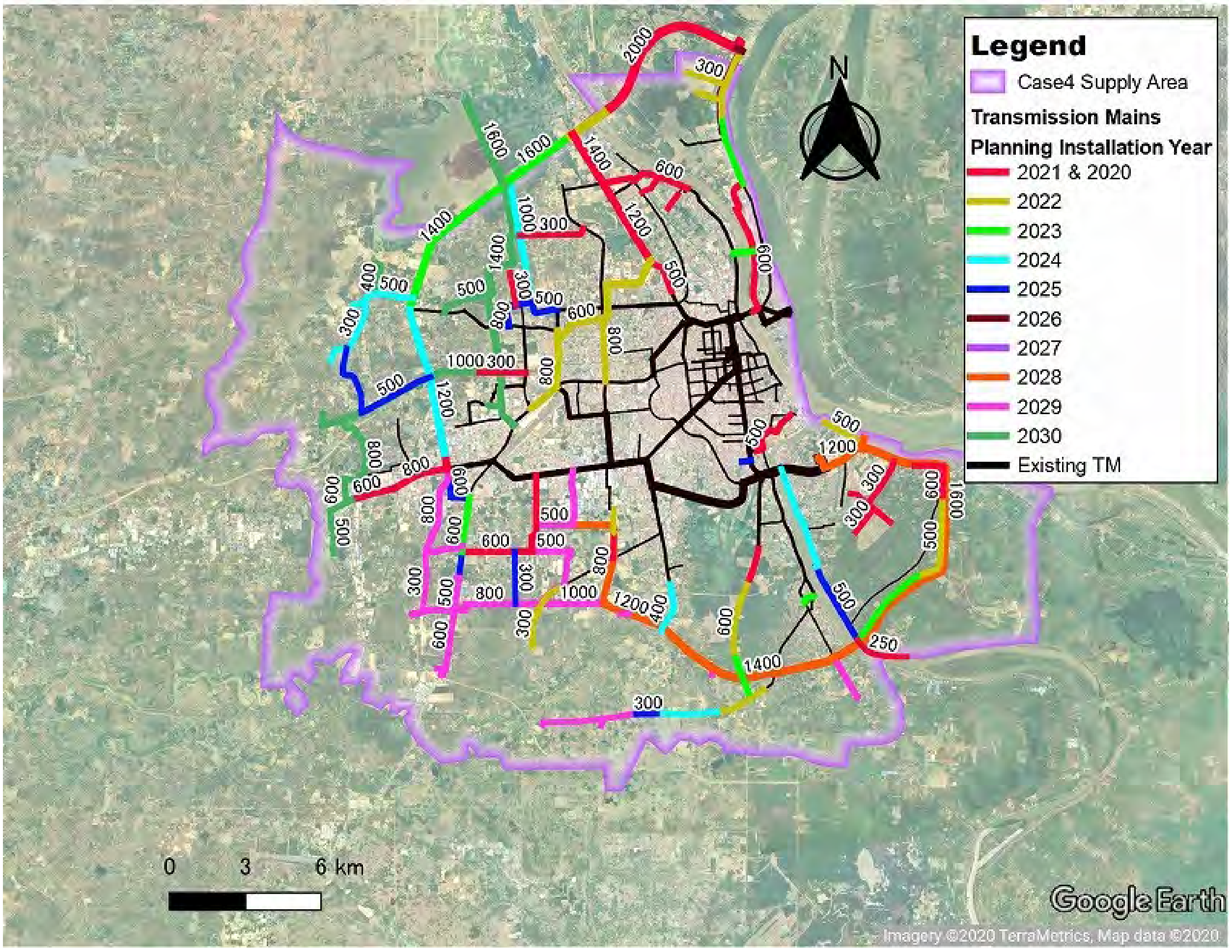


Figure 7.2.23 Water Supply Area Development Plan for Case 4
Source: JICA Data Collection Survey Team based

(e) Case 5

Figure 7.2.24 shows details of Case 5: Large-Scale Development Project Group 1 and Group 2 (excluding 2-9 Preaek Ta Teaen, Vihear Luong, Ponhea Lueu, Phsar Daek, Kampong Luong, Chhveang, Phnum Bat, Chrey Loas) are added to the PPWSA service area.

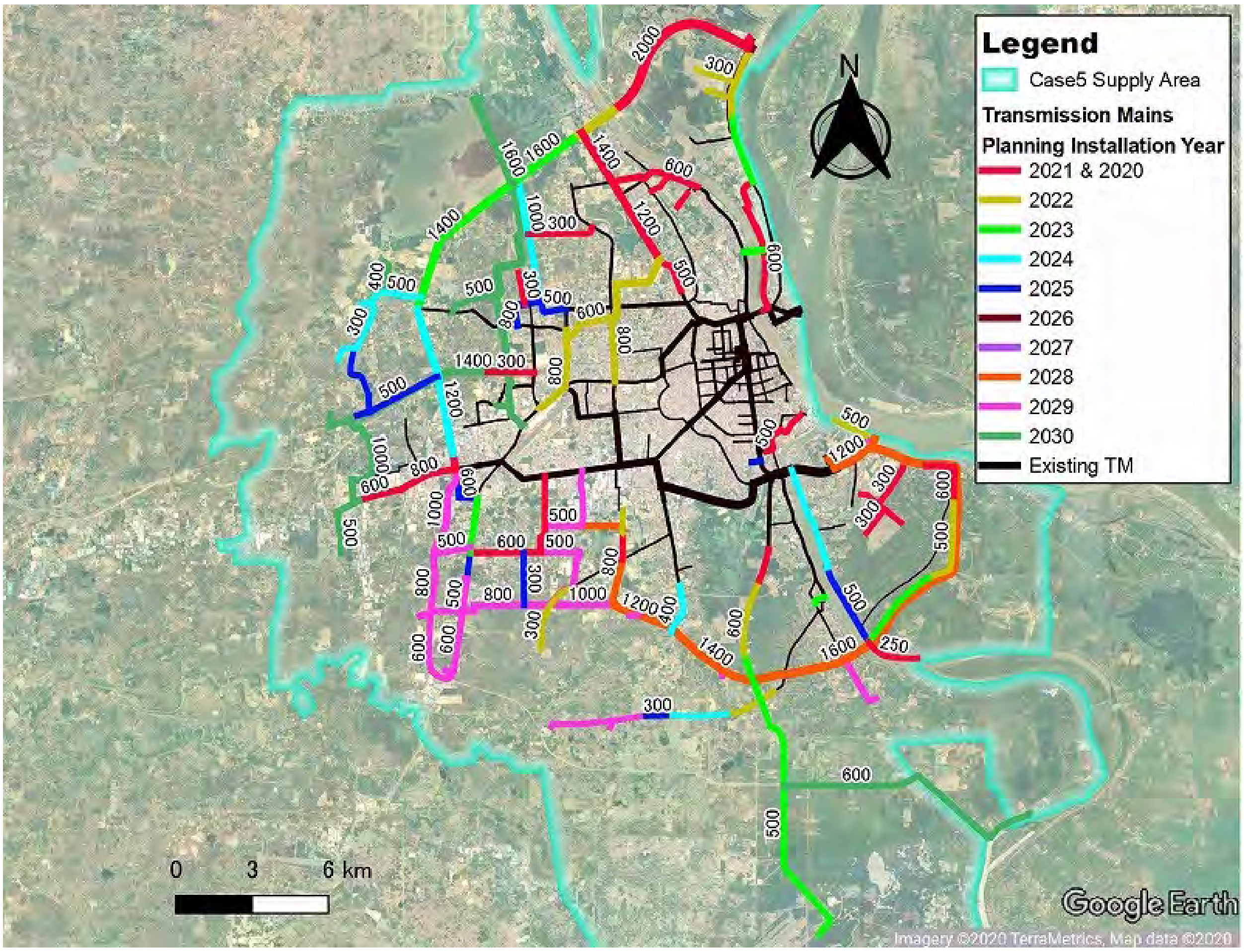


Figure 7.2.24 Water Supply Area Development Plan for Case 5
Source: JICA Data Collection Survey Team based

(f) Case 6

Figure 7.2.25 shows details of Case 6: Large-Scale Development Project Group 1, Group 2, and Group 3 are added to the PPWSA service area and Boeng Thom WTP is also constructed.

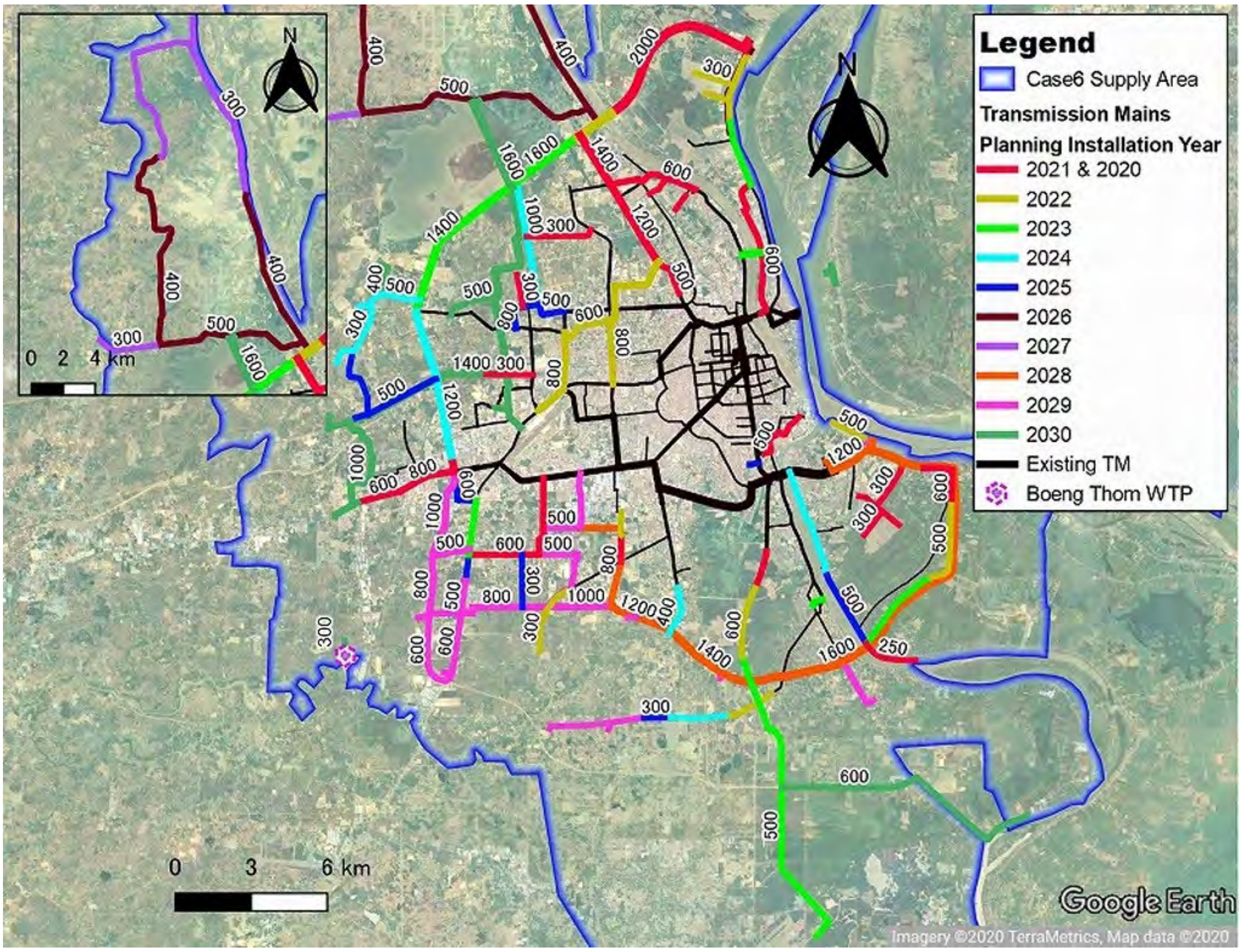


Figure 7.2.25 Water Supply Area Development Plan for Case 6

Source: JICA Data Collection Survey Team based

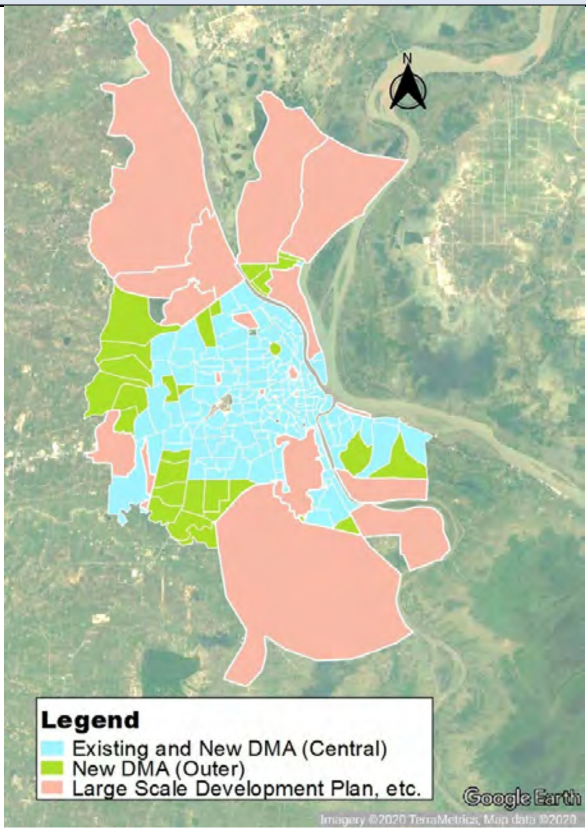
7.2.2 Distribution Network Expansion Plan

(1) Distribution Network Expansion Plan

1) Distribution Network Expansion Policy

Table 7.2.11 shows the expansion policy of the distribution network expansion plan. The policy includes improving the capacity of distribution mains and improving the capacity of existing pipes to meet future water demand.

Table 7.2.11 Policy for Expansion of Distribution Main Lines

Policy		Details	
Improve capacity of distribution mains	New and existing DMAs in the urban center.	Based on the revised water demand for 2030, check water volume and pressure of DMAs in 2030 and verify whether existing distribution mains have sufficient capacity. If not, increase pipe size, lay multiple pipes, or loop pipes to meet demand.	
	New DMAs in the surrounding areas	For new DMAs in the surrounding areas, the number of connections is expected to increase as development continues. The conditions of neighboring DMAs will be considered when deciding expansion of distribution mains of new DMAs.	
	Large-scale development projects	Large-scale development areas will be handled as bulk supply. A branch from the transmission line will be provided to the DMA inlet point.	
Improve capacity of distribution pipes	Looping of pipes	For existing pipes, create loops in the network to effectively utilize water pressure and volume.	
	Replacement of old pipes	Replace pipes based on service life.	
	Strategic replacement of water meters	Strategically replace water meters, considering the growth in the number of connections.	

Source: JICA Data Collection Survey Team

2) Planning Factors

Planning factors for water distribution network expansion are shown in ***Table 7.2.12***. Details are given in the ***Appendix***.

Table 7.2.127.2.13Planning Factors for Water Distribution Network Expansion Plan

Item	Details
Supply area	Phnom Penh and surrounding large-scale development areas (Kandal Province)
Water demand	1,814,000 m^3/day (2030 water demand, day max)
Peak factor	1.60
Minimum pressure	>2 bar at distribution main line terminus
DMA	184 DMAs + 19 large-scale development areas
Hydraulic analysis software	WaterGEMS

Equation	Hazen Williams
Coefficient of velocity (C-value)	130
Pipe material	Diameter ≥ 300 mm: Ductile Iron Diameter < 300mm: HDPE (PPWSA standard)

Source: JICA Data Collection Survey Team

Whether or not the distribution mains in the existing DMAs can secure sufficient water pressure and flow for the revised demand in 2030 will be verified (***Figure 7.2.26***). If the capacity of the water distribution main is insufficient, measures such as increasing the diameter or installing multiple lines are proposed. A pressure of 2.0 bar or greater shall be maintained at the terminus of the distribution main. The method and results of hydraulic analysis are shown in the ***Appendix***.

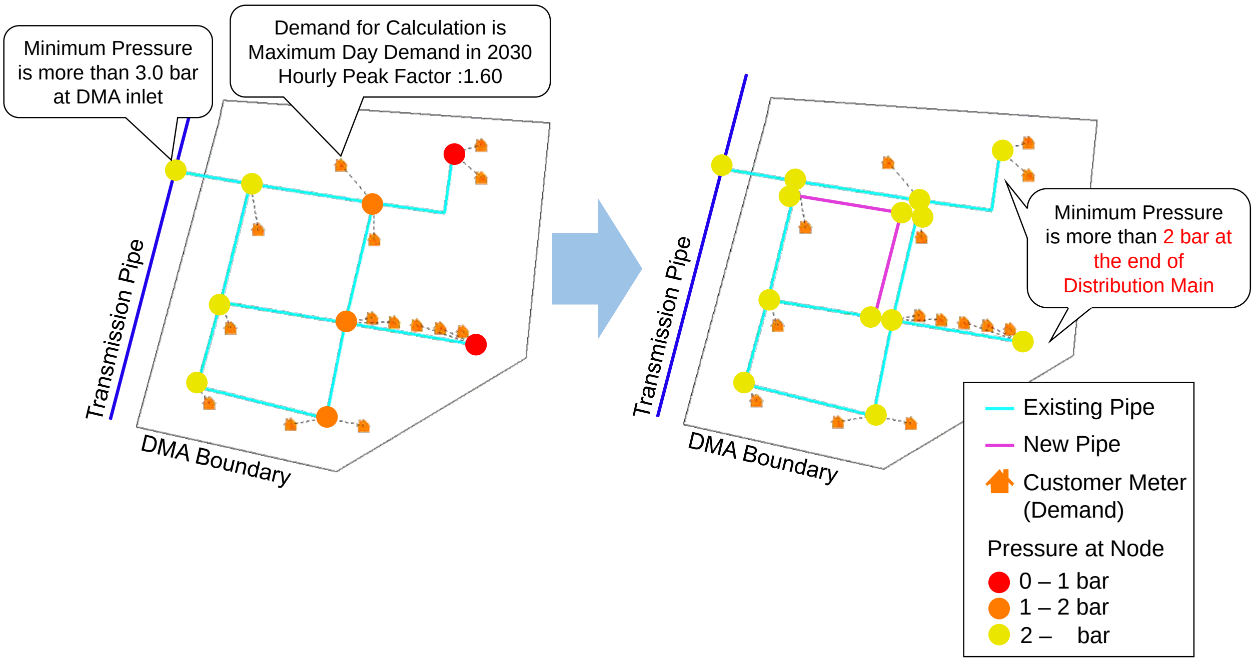
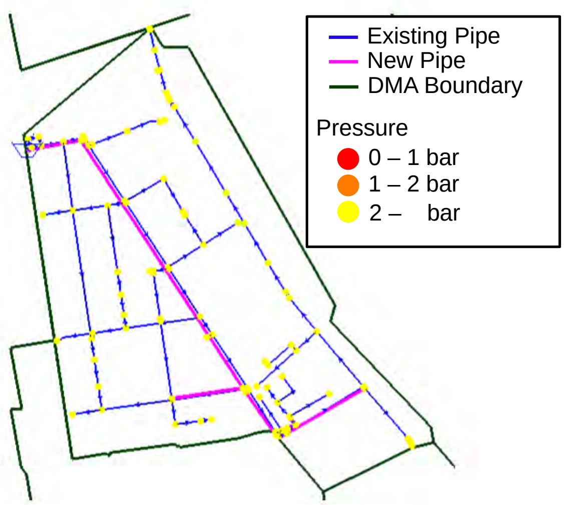


Figure 7.2.267.2.27 Summary of Distribution Network Expansion Plan
Source: JICA Data Collection Survey Team

(2) Reinforcement of Distribution Main Lines

The capacities of the water distribution mains were confirmed using the water demand of 2030. ***Figure 7.2.28*** shows the results of DMA101 as an example. Confirmation results of other DMAs are available in the ***Appendix***



Diameter (mm)	Length (m)
160	180
225	81
300	1,306
Total	1,567

Figure 7.2.28 Result of Survey of DMA (0101)
Source: JICA Data Collection Survey Team

Based on the results of the network capacity confirmation above, a list of distribution mains that require multiple lines is shown in ***Table 7.2.14***.

Table 7.2.14 List of Distribution Mains Improvement Plans

DMA	Diameter (mm)	Length (km)	DMA	Diameter (mm)	Length (km)	DMA	Diameter (mm)	Length (km)
101-107 (2026)	300	4.33	601-616 (2024,2028)	110	5.21	1001-1013 (2023-2025)	110	41.49
				160	4.14		160	36.36
201-205 (2026)	250	0.05		225	11.60		225	17.85
	300	4.42		250	0.39		250	6.40
301-315 (2026)	110	0.42		300	24.23		300	20.24
	160	0.23	701-721 (2023-2029)	110	40.50	1101-1113 (2027-2028)	110	20.80
	225	3.74		160	34.03		160	20.90
	250	0.87		225	22.88		225	14.15
	300	15.62		250	6.09		250	10.21
401-410 (2026)	110	0.17		300	37.61		300	20.23
	160	0.38	801-841 (2023-2030)	110	65.83	1201-1203 (2023-2024)	110	2.52
	225	7.14		160	56.30		160	3.74
	250	2.93		225	62.89		225	3.10
	300	6.19		250	30.94		250	0.39
501-510 (2024,2026)	110	4.96		300	92.00		300	1.24
	160	3.72	901-923 (2023,2027)	110	1.69	1301-1307 (2023,2029)	110	9.39
	225	3.30		160	6.17		160	9.27
	250	6.85		225	4.84		225	8.18
	300	15.84		250	3.84		250	2.99
				300	16.93		300	17.44

Source: JICA Data Collection Survey Team

Water is being supplied by private enterprises around the administrative divisions of Phnom Penh and Kandal Province. If these areas join the PPWSA supply area, the water required in these areas will depend on their development status at that time and establishment of DMAs and expansion of the pipe network may be necessary. In this survey, the unit expansion volume (4.67 m/(m^3/day)) was estimated based on pipe installation conditions and road conditions of neighboring DMAs. When a DMA is added to the water supply area, the scale of expansion required based on the development status must be reviewed.

(3) Improvement of Distribution Lines

1) Looping of Distribution Lines

As shown in ***Figure 7.2.29***, water distribution pipes have been installed in branches in response customers' requests to be connected to the network and other ad hoc needs. Therefore, there are places in the network where the distribution pipes do not form a loop. This is an inefficient arrangement and as a result, there are places where water pressure insufficient. As in the Third Master Plan (M/P2017), this survey proposes to improve water pressure by completing the loops in the network in the 10 years until 2030.

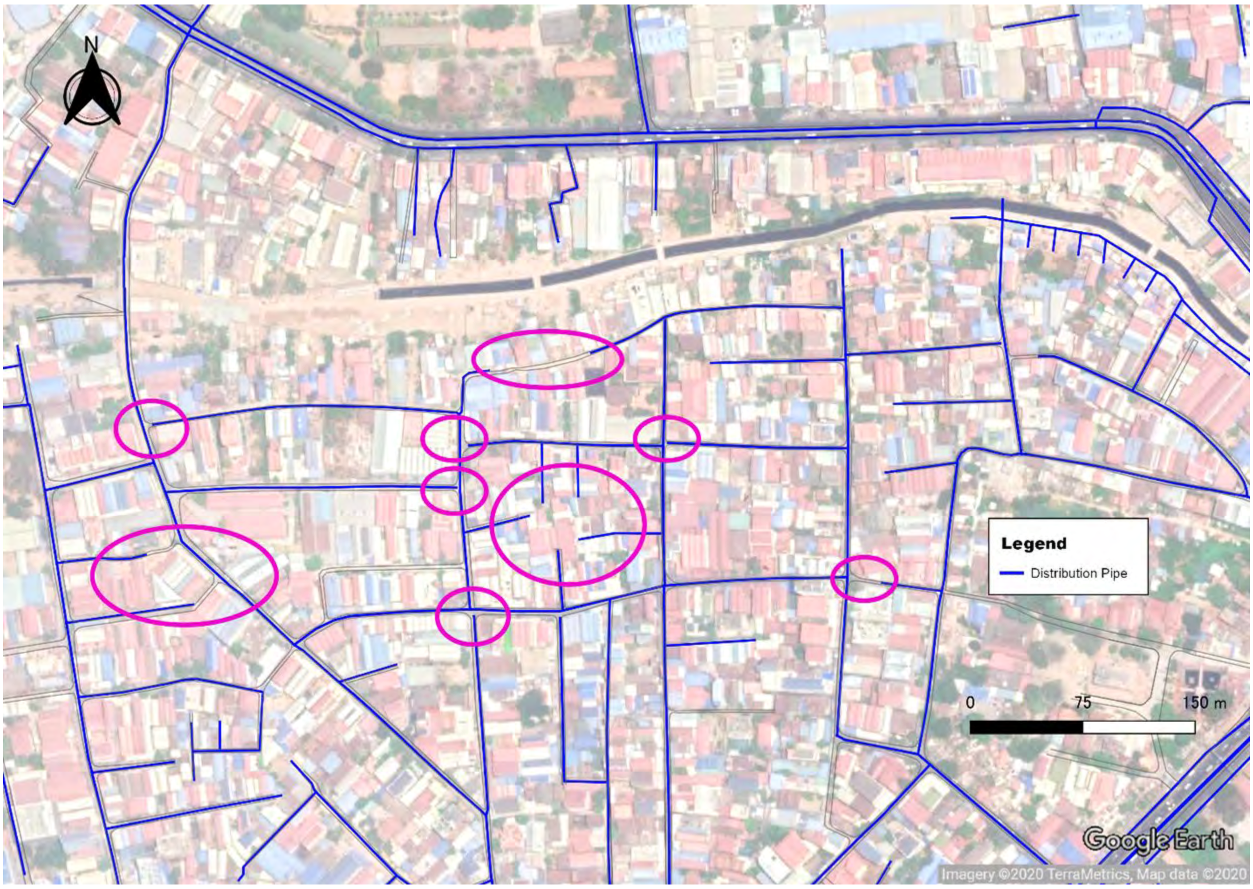
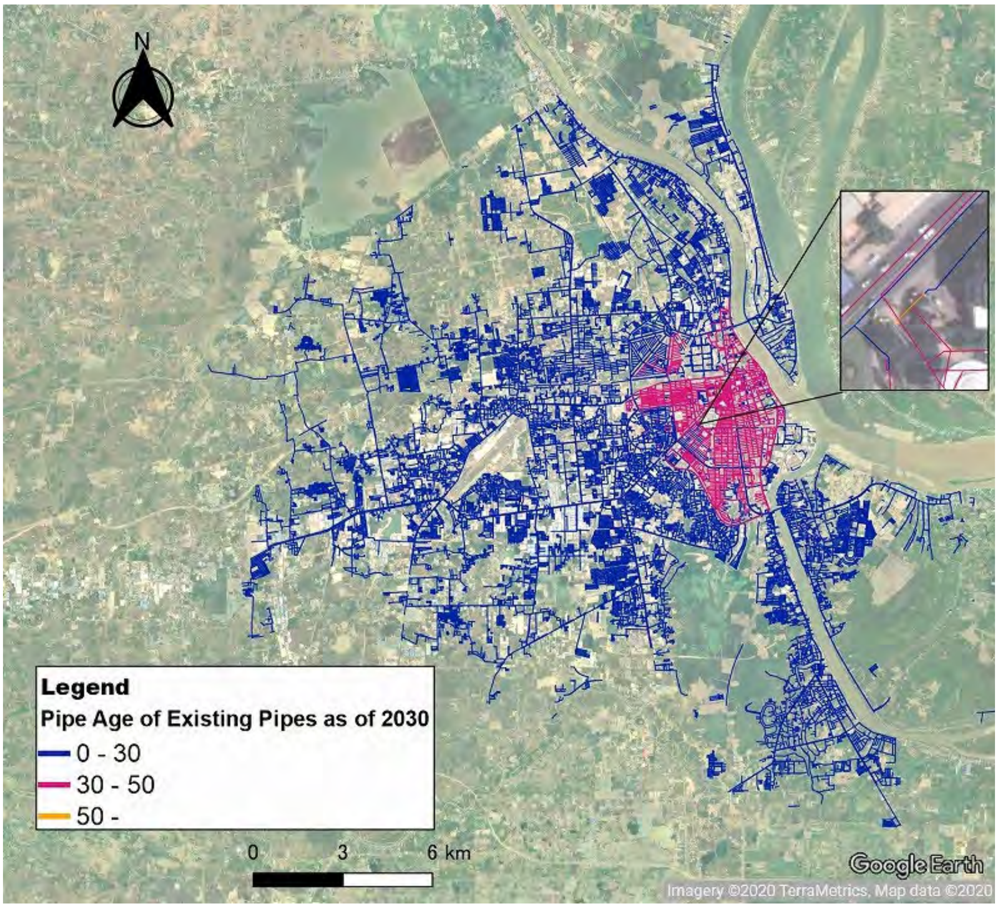


Figure 7.2.29 Summary of Looping of Distribution Lines
Source: JICA Data Collection Survey Team based on PPWSA annual plan

2) Replacement of Aging Pipes

(a) Replacement of Aging Pipes

Pipes at the end of their design life in 2030 are shown in ***Figure 7.2.30***. The installed length of these pipes is shown in ***Figure 7.2.31***.



Age at 2030	Length (km)
30～50 year	354
Over 50 years	0.01

Figure 7.2.30 Distribution of Aging Pipes in 2030
Source: JICA Data Collection Survey Team

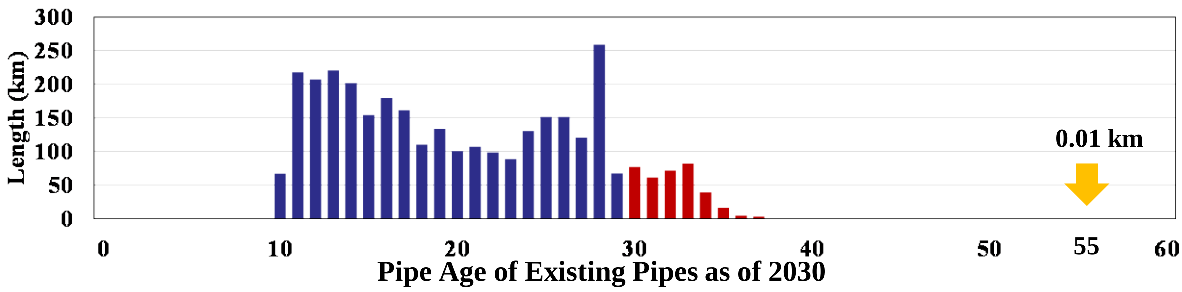


Figure 7.2.31 Installed Length of Aged Pipes in 2030
Source: JICA Data Collection Survey Team

PPWSA sets the life of pipes at 30 to 50 years and replaces them as a part of the pipe maintenance works. Pipes that will be 50 years old in 2030 will need to be replaced. However, the amount is very small.

Many of the pipes in the Phnom Penh urban center (Khan Daun Penh, Khan Prampir Makara, Khan Chamcar Mon, Khan Tuol Kouk) will be over 30 years old in 2030 and a plan to replace 350 km of pipes will be needed. In the future, more and more pipes will need to be replaced. Daily maintenance and repair records should be evaluated and accumulated, and a medium-term plan for pipe replacement should be created.

(b) Leakage repair and replacement

The leakage density (leakages/km) of each Sangkat is shown in ***Figure 7.2.32***.

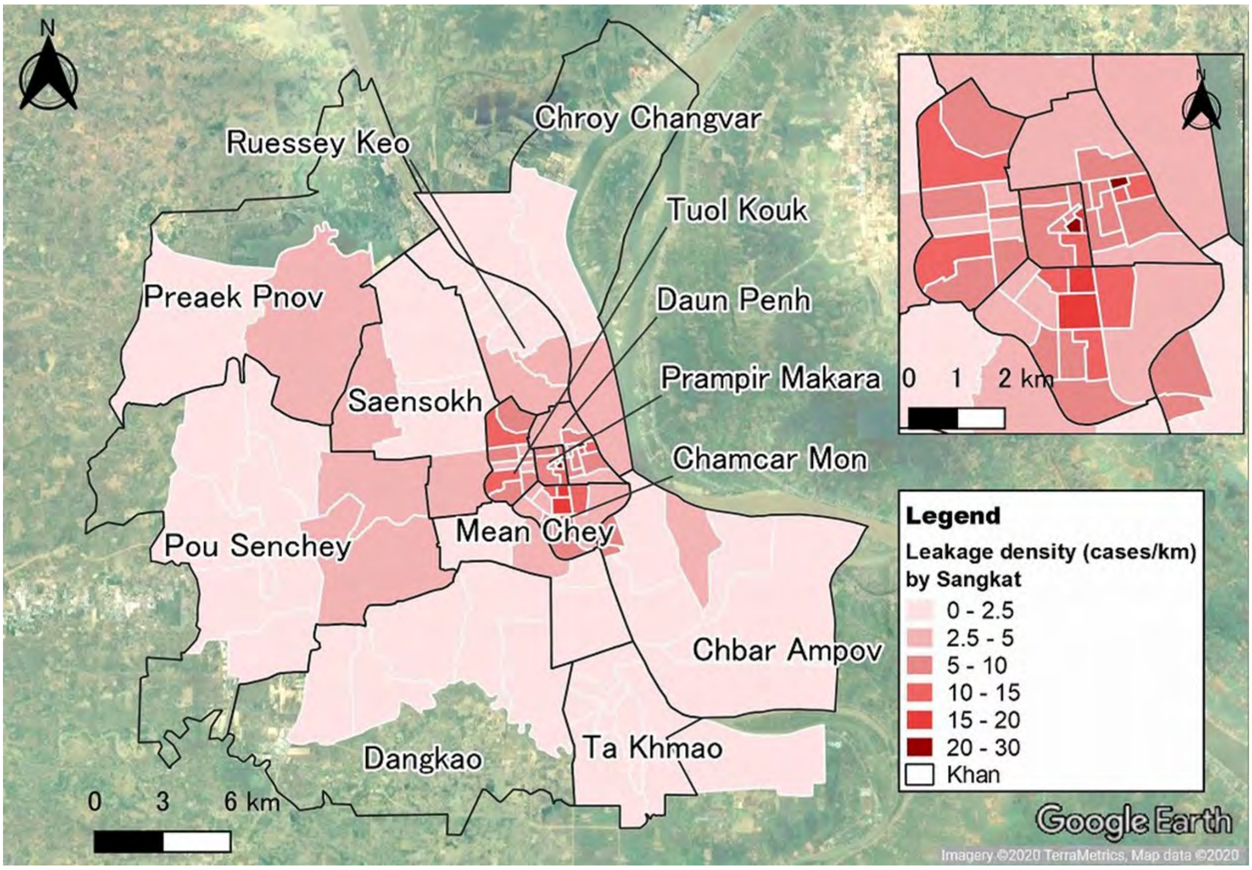


Figure 7.2.32 Leakage Density
Source: JICA Data Collection Survey Team

About 40% of leaks are located in the urban center (Khan Daun Penh, Khan Prampir Makara, Khan Chamcar Mon, Khan Tuol Kouk) where old pipes are abundant. Therefore, replacement of aged pipes in this area should be prioritized.

3) Improvement of Distribution Lines

In addition to the capacity improvements of existing pipes discussed above, installation of distribution branches, water supply lines, and improvement of lines will be needed to accommodate the increasing demand in the future.

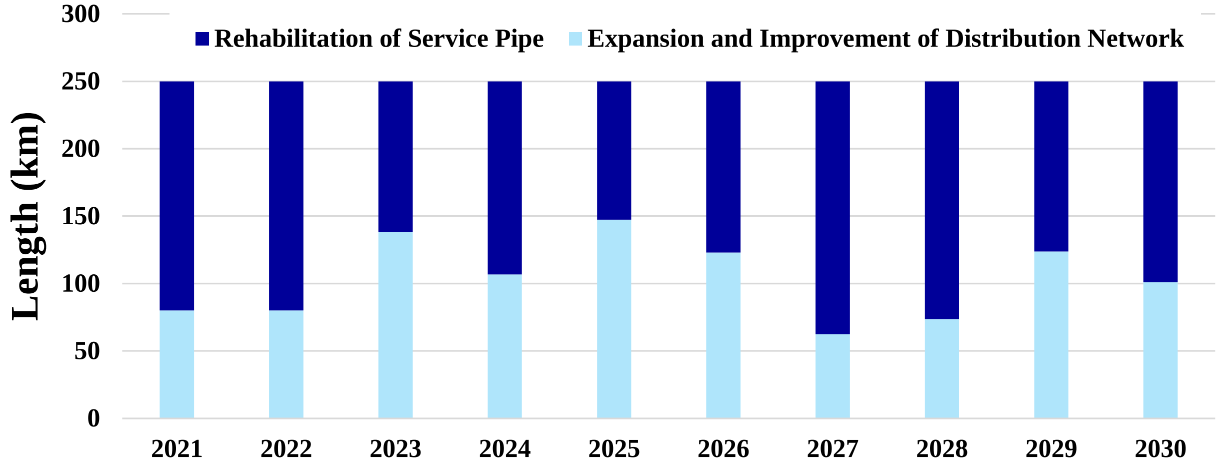


Figure 7.2.33 Distribution of Aging Pipes in 2030
Source: JICA Data Collection Survey Team based on PPWSA annual plan

4) Strategic Replacement of Customer Water Meters

PPWSA replaces customer water meters after 11 years of use. Currently, about 20,000 water meters are replaced every year. A water meter replacement plan up to 2030 using the revised water demand is proposed, as shown in ***Figure 7.2.34***.

In the new plan, approximately 30% of the water meters are to be replaced in 2021. After 2021, water meters must be replaced along with these installed one cycle earlier. After 2026, roughly 28,000 water meters should be replaced, far beyond the 20,000 meters that is currently planned.

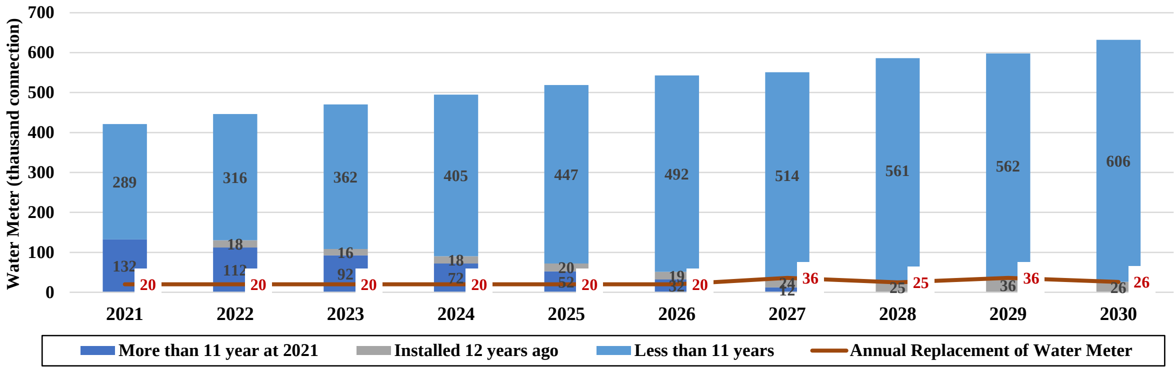


Figure 7.2.34 Water Meter Replacement Plan
Source: JICA Data Collection Survey Team based on PPWSA annual plan

(4) Improvement of Operational Management of the Transmission Network
In the transmission network expansion plan and the distribution network expansion plan, facility development to meet future water demand was proposed in this report. Although it is expected that water shortages will be resolved by completing the facility expansion projects and securing additional water supply, these will not be completed until 2030. Until then, it is expected that the supply of water will continue to be insufficient. It will be important to strengthen the management of water volume and water pressure and keep the non-revenue water rate low.

So far, PPWSA has concentrated on replacement of old pipes, replacement of water meters, leak detection and repair, etc. as the main measures against NRW. In the future, it will be necessary to strengthen and implement these measures. At the same time, PPWSA must also take measures against service disruptions in the face of supply shortages and disruptions due to the increase in old pipes and insufficient production capacity. Therefore, it is necessary to effectively and efficiently operate the system using the SCADA system and accumulated data.

CHAPTER 8 PROPOSED IMPLEMENTATION PLAN

8.1 STAGED DEVELOPMENT PLAN AND IMPLEMENATION SCHEDULE

8.1.1 Overall Development Plan

The years from 2021 to 2030 are divided into three periods as listed below. Developments required beyond the target year are planned in phases beyond 2030.

i. Immediate Period (2021-2024)
ii. Intermediate Period (2025-2027)
iii. Ultimate Period (2028-2030)
iv. After 2030

The water demand projected in the Third Master Plan (M/P 2017) and this MPU2022 are compared in ***Table 8.1.1***.

Table 8.1.1 Overall Staged Development Plan

Scheme	Year									
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Phum Prek WTP	150,000	150,000	150,000	150,000	150,000	195,000	195,000	195,000	195,000	195,000
Churoy Chamber WTP	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000
Chamkar Mon WTP	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
Nirodh WTP	260,000	260,000	260,000	260,000	260,000	260,000	260,000	260,000	390,000	390,000
Bakheng WTP	0	0	390,000	390,000	390,000	390,000	585,000	585,000	585,000	585,000
Ta Khmao WTP	0	0	0	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Koh Norea WTP	0	0	0	0	0	0	0	0	150,000	150,000
Ta Mouk WTP	0	0	0	0	0	0	0	0	0	200,000
New Airport City	0	0	0	0	0	0	0	0	0	30,000
Khsach Kandal WTP	0	0	0	0	0	0	0	0	0	100,000
Total Production Capacity (All)	**592,000**	**592,000**	**982,000**	**1,012,000**	**1,012,000**	**1,057,000**	**1,252,000**	**1,252,000**	**1,532,000**	**1,862,000**
Total Production Cap. (Exc G3)	**592,000**	**592,000**	**982,000**	**1,012,000**	**1,012,000**	**1,057,000**	**1,252,000**	**1,252,000**	**1,532,000**	**1,762,000**
Total Max. Day Demand (MP2017)	805,676	849,032	893,053	930,565	969,514	1,002,119	1,027,949	1,051,810	1,072,340	1,093,050
Total Ave. Day Demand (MP2017)	700,587	738,288	776,568	809,187	843,056	871,408	893,869	914,618	932,470	950,478
Total Max. Day Demand (Basic)	**656,830**	**724,523**	**879,869**	**982,911**	**1,063,413**	**1,145,438**	**1,213,942**	**1,282,364**	**1,342,726**	**1,402,540**
Total Max. Day Demand (B+G1)	**667,808**	**737,960**	**902,955**	**1,024,006**	**1,116,894**	**1,216,584**	**1,301,978**	**1,401,918**	**1,498,894**	**1,613,845**
Total Max. Day Demand (B+G1+G2)	**668,000**	**738,000**	**903,000**	**1,025,000**	**1,189,750**	**1,294,867**	**1,385,984**	**1,492,099**	**1,594,217**	**1,716,333**
Total Max. Day Demand (B+G1+G2+G3)	**668,000**	**738,000**	**903,000**	**1,025,000**	**1,263,000**	**1,373,000**	**1,469,000**	**1,580,000**	**1,687,000**	**1,814,000**
Total Ave. Day Demand (B+G1+G2+G3)	**581,000**	**642,000**	**786,000**	**891,000**	**1,098,000**	**1,194,000**	**1,277,000**	**1,374,000**	**1,467,000**	**1,578,000**
Total Ave.. Day Demand (Exc G3)	**581,000**	**642,000**	**786,000**	**891,000**	**1,034,304**	**1,126,058**	**1,204,812**	**1,297,564**	**1,386,319**	**1,493,072**
Total Max. Day Demand in Existing Area	**641,179**	**700,957**	**844,262**	**935,612**	**1,003,824**	**1,072,648**	**1,127,895**	**1,182,383**	**1,229,129**	**1,275,143**
Total Max. Day Demand in New Area	**26,821**	**37,043**	**58,738**	**80,388**	**188,176**	**223,352**	**259,105**	**308,617**	**363,871**	**438,857**
Temporary Reduction of PPWTP	**0**	**0**	**0**	**0**	**0**	**50,000**	**50,000**	**500,000**	**50,000**	
Gap between Total Production Capacity and Total max. Day Demand	-76,000	-146,000	79,000	-13,000	-251,000	-316,000	-217,000	-328,000	-155,000	48,000
Gap between Total Production Capacity and Total Ave. Day Demand	11,000	-50,000	196,000	121,000	-22,304	-69,058	47,188	-45,564	145,681	368,928

Source: JICA Data Collection Survey Team

The overall staged development plan needs to meet forecast water demand as shown in ***Figure 8-1.1***. Each stage is divided into phases according to proposed WTP development schedules. The total production capacity of WTPs cannot meet overall water demand in the PPWSA coverage area until 2030 due to timeframe requirements of WTP development such as funding, preparation, design, and construction.

As discuss in the ***Section 4.3.7***, grouping of the planned and potential large-scale development is as shown in ***Table 8.1.2*** and ***Figure 8.1.1***.

Table 8.1.2 Grouping Large-Scale Development Plans

GROUP	DESCRIPTION
Group 1	Large-scale development plans − which have been already started − which will be started soon
Group 2	Large-scale development plans or areas currently supplied by private utilities − they are located in the west side of the Mekong River − There are uncertainties of whether: ➢ the project will be carried out or not ➢ they will continue to be supplied by private utilities continuously or be supplied by PPWSA in the future
Group 3	Areas currently supplied by private utilities − they are located in the east side of the Mekong River − There are uncertainties of whether: ➢ they will continue to be supplied by private utilities continuously or be supplied by PPWSA in the future

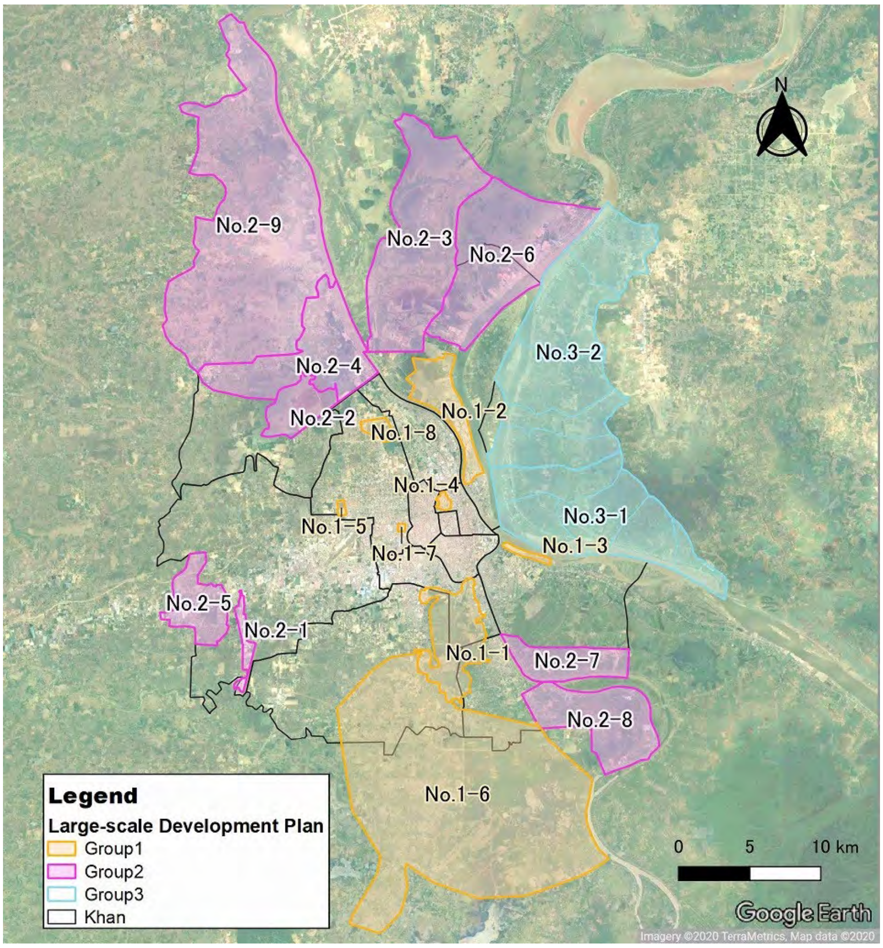


Figure 8.1.1 Location of Projects/Areas of the Group 1,2 and 3

Source: Prepared by JICA Data Collection Survey Team based on the information provided by PPWSA

Figure 8.1.3, ***Figure 8.1.4***, and ***Figure 8.1.5*** show the staged development plan in case considering basic water demand and water demand in G-1, in case considering basic water demand and water demand in G-1 and G-2, and in case considering basic water demand and water demand in G-1 and G-3, respectively. In these cases, Kasach Kandal and/or New Airport WTP Schemes are not implemented. However, other large-scale WTP schemes are necessary as when water demand of all groups is considered.

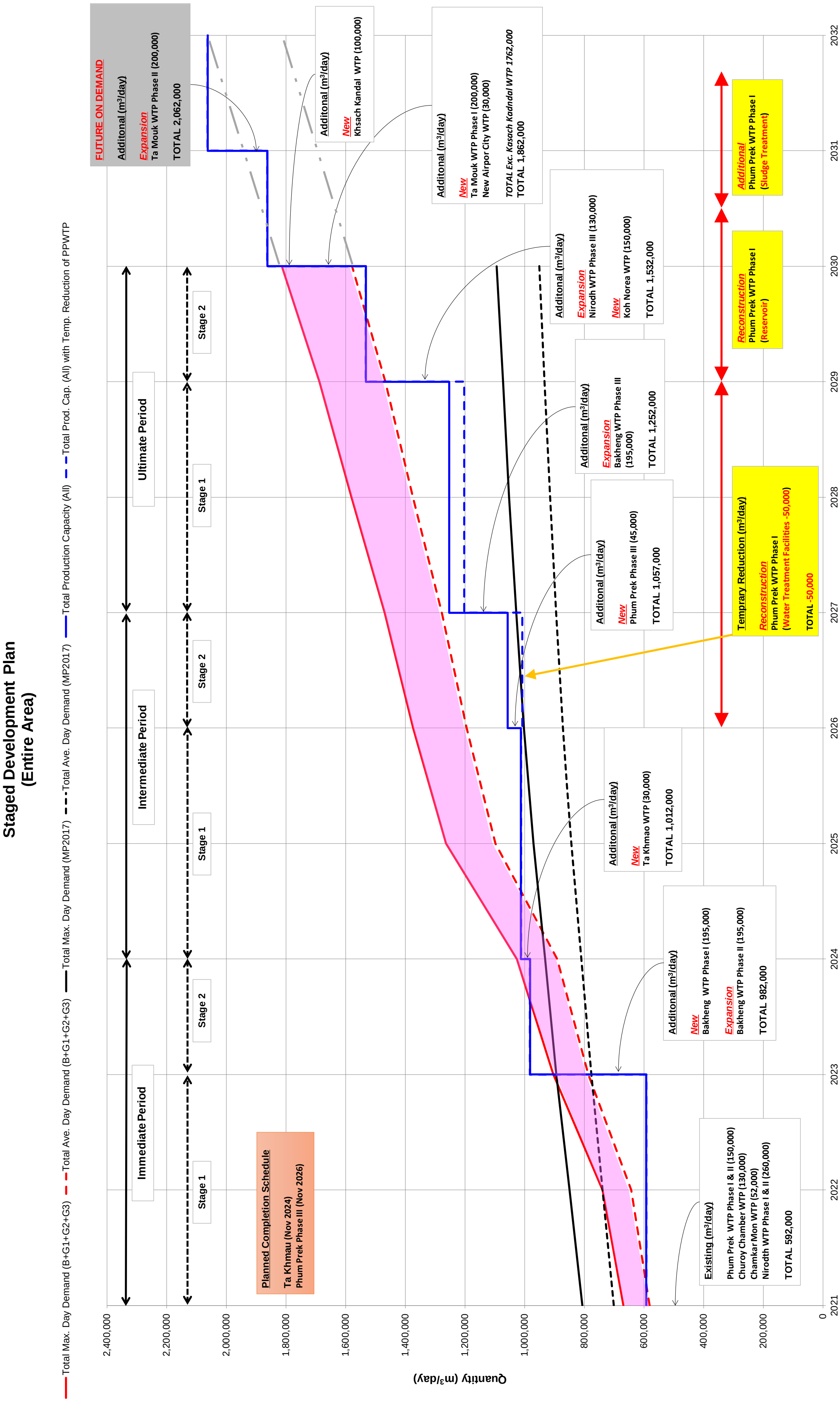


Figure 8.1.2 The Overall Staged Development Plan
Source: JICA Data Collection Survey Team

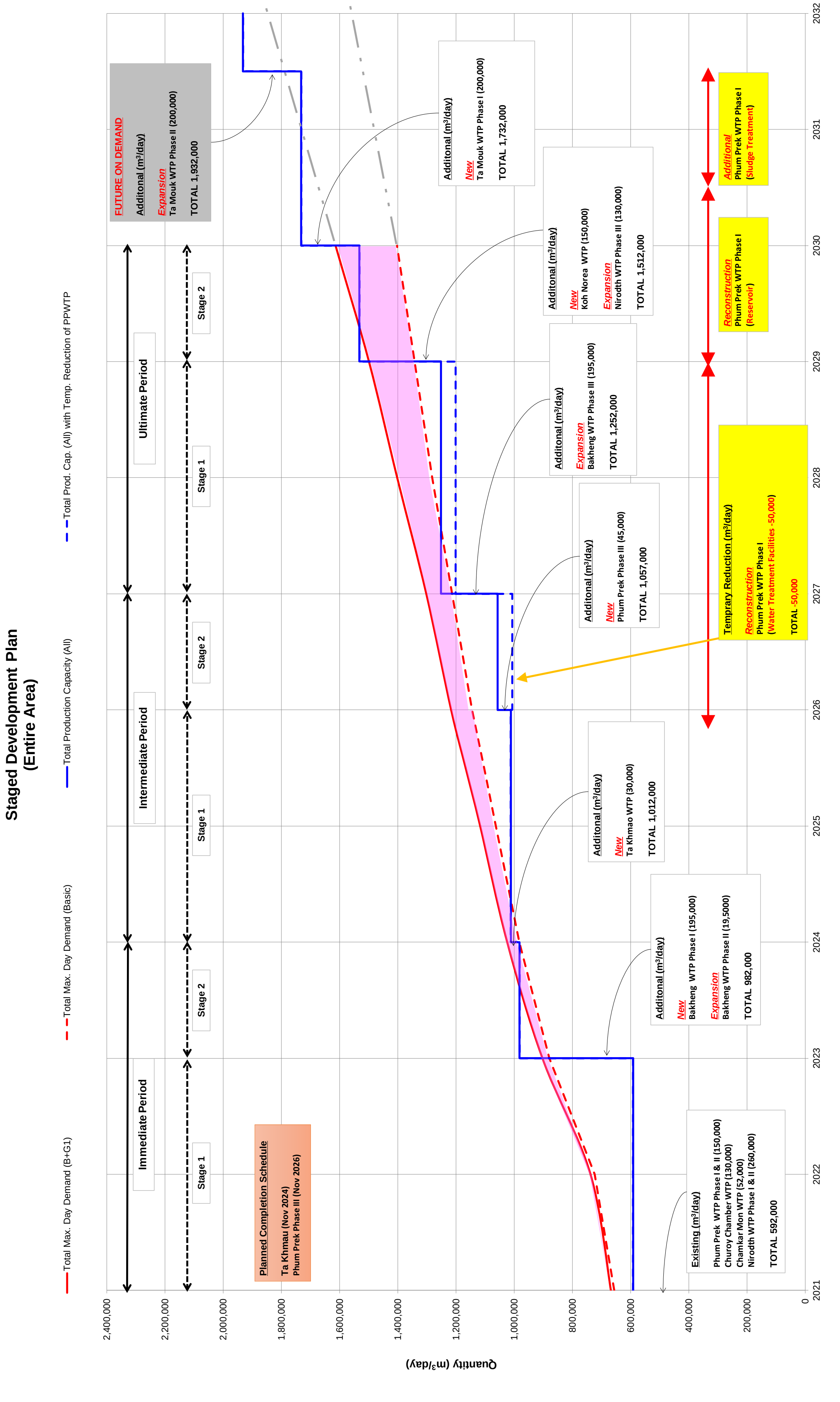


Figure 8.1.3 The Overall Staged Development Plan (in case considering basic water demand and water demand for G-1)

Source: JICA Data Collection Survey Team

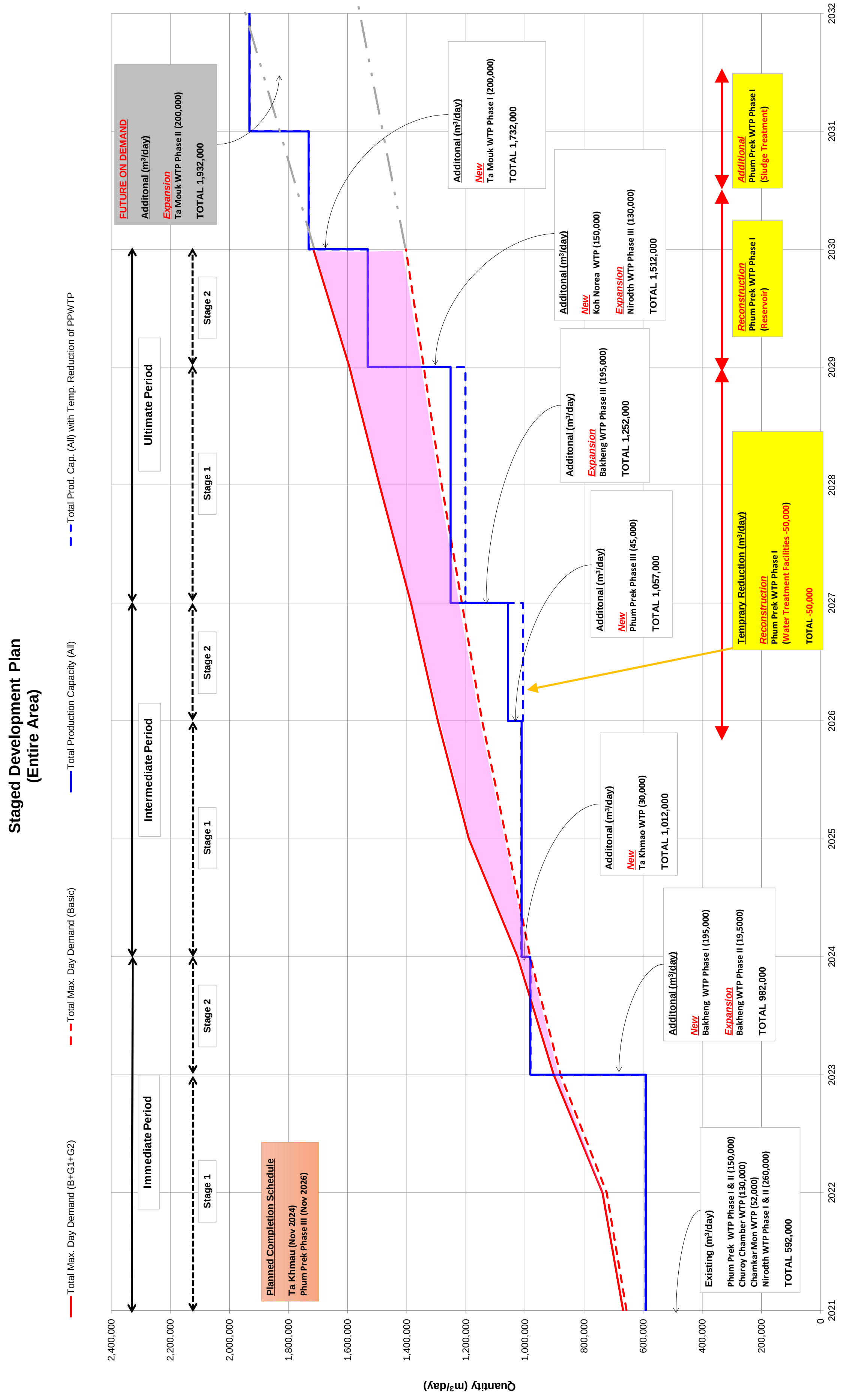


Figure 8.1.4 The Overall Staged Development Plan (in case considering basic water demand and water demand for G-1 and G-2)

Source: JICA Data Collection Survey Team

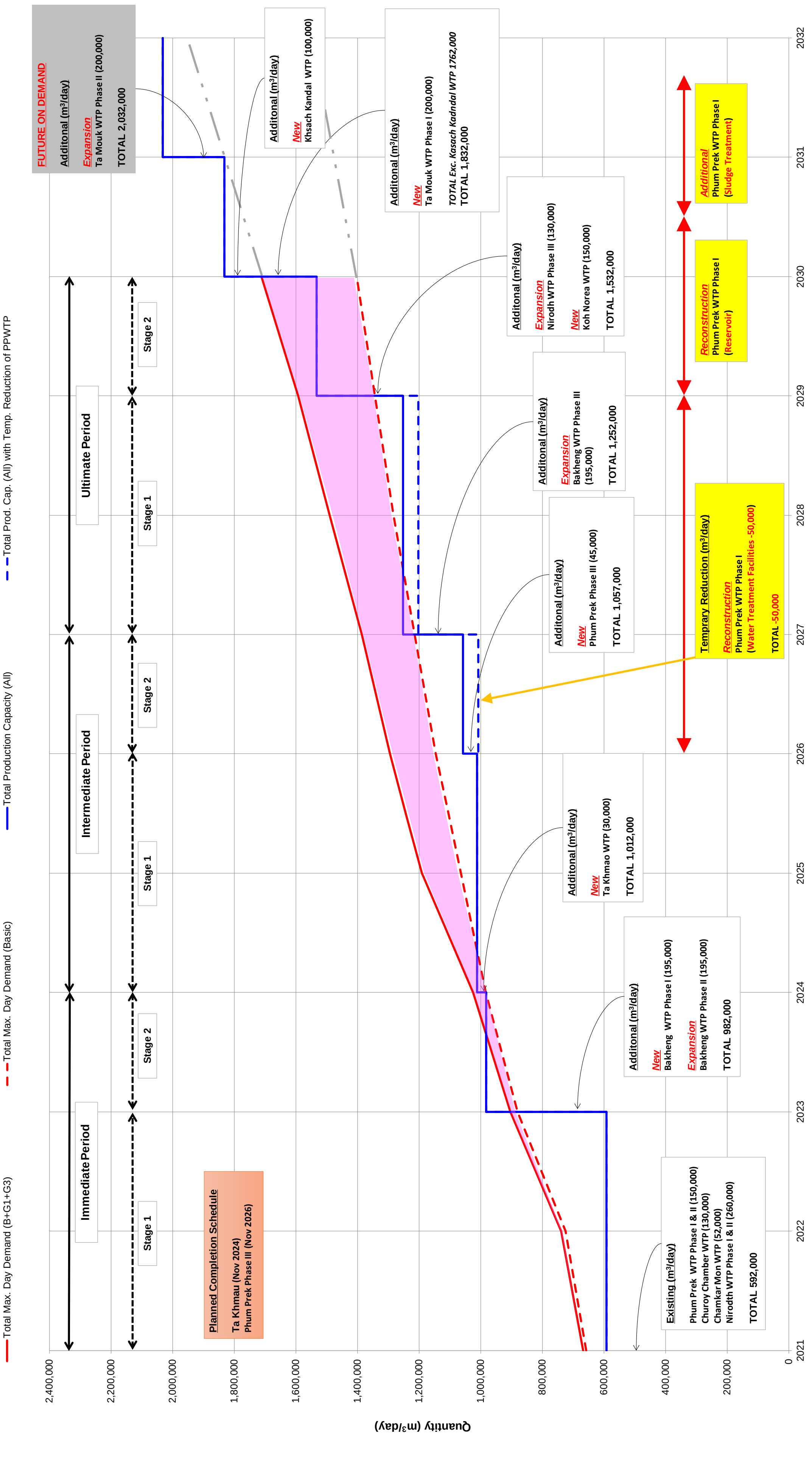


Figure 8.1.5 The Overall Staged Development Plan (in case considering basic water demand and water demand for G-1 and G-3)
Source: JICA Data Collection Survey Team

A design-build projects by a joint venture between Suez and Vinci companies financed by AfD support for the construction of Bakheng WTP Phase I and Phase II are currently being planned and the implementation schedule is mostly confirmed.

The renovation of the Phum Prek Phase I WTP will start after the construction of Phum Prek Phase III is completed. This will allow all existing facilities to keep operating and producing water so the amount of water supplied to the service area is not reduced during the expansion project.

It was reported that in June 2021, the Minister of MISTI met with the French Ambassador to Cambodia and discussed the French Government implementation of the Bakheng Phase III Project. Therefore, this survey includes the implementation of the Bakheng Phase III Project to meet the water demand of 2027 in areas other than the G3 region in order to resolve water shortages as soon as possible.

Construction of other WTPs is predicted to be completed in 2029 at the earliest. Implementation of these projects is expected to take longer since commitments as those made for the Bakheng Phase III Project have not yet been confirmed.

In addition, simultaneous implementation of multiple WTP construction projects is imagined to be difficult due to the limited financial and project implementation capacity of PPWSA. Therefore, project implementation is divided into Stage 1 and Stage 2 for development planning.

Through this logic, and with a focus on improving water supply and increasing water supply rate in the existing water supply area, development of Niroth Phase III and Koh Norea WTP is proposed during Stage 1. Following this stage, Ta Mouk Phase I and Phase II (which mainly belong to Group 2 and Group 3) and the Kasack Kandal WTP Projects will be implemented in Stage 2 of the Ultimate Period. Regarding the New Airport City WTP scheme, water can be supplied to the area from Niroth for some time. Therefore, the implementation of the New Airport City WTP scheme can be modified based on future water supply conditions and needs, and implementation during Stage 2 was proposed.

8.1.2 Immediate Period

The first period has been designated as the "Immediate Period". The immediate period will be until 2024 and aims to complete projects that are currently under implementation or planning. However, it should be noted that completion may be delayed due to the impacts of COVID-19.

(1) Stage 1

1) Bakheng Phase I

a) Project Contents

Table 8-1.2 outlines the contents of the Bakheng Phase I Project. The planned production capacity is 195,000 m^3/day. It is currently being implemented with support from AfD.

Table 8.1.3 Contents of the Bakkhend Phase I Project

Period	Stage	Project	Component	Contents
Immediate Period	Stage 1	Bakheng Phase I	Water Treatment Plant	Production Capacity: 195,000 m^3/day New construction of intake, transfer main, WTP, reservoir, distribution pumps
			Transmission Mains Distribution Mains	Transmission mains (Phase I and Phase II total 110 km, Sap River crossing with tunnelling method) and distribution mains
			Capacity Building	Water quality analysis water supply management

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.4 shows the implementation schedule of the Bakheng Phase I Project. Initial construction was scheduled to be completed in 2022. However, due to the delays caused by the effects COVID -19, construction is scheduled to be completed in 2023.

Table 8.1.4 Implementation Schedule of the Bakheng Phase I Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Design & Build										

Source: JICA Data Collection Survey Team

2) Bakheng Phase II

a) Project Contents

Table 8.1.5 outlines the contents of the Bakheng Phase II Project. The planned production capacity is 195,000 m^3/day. This project is also scheduled to be implemented with the support of AfD, and loan agreement discussions were underway as of 2021.

Table 8.1.5 Contents of the Bakheng Phase II Project

Period	Stage	Project	Component	Contents
Immediate Period	Stage 1	Bakheng Phase II	Water Treatment Plant	Production Capacity: 195,000 m^3/day Expansion of intake, transfer main, WTP, reservoir, distribution pump capacities
			Transmission Mains	Transmission mains (Phase I and Phase II total 110 km, Sap River crossing with tunnelling method) and distribution mains.
			Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.6 shows the implementation schedule of the Bakheng Phase II Project. According to PPWSA, the Bakheng Phase II Project is scheduled to be completed in 2023.

Table 8.1.6 Implementation Schedule of the Bakheng Phase II Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Design & Build										

Source: JICA Data Collection Survey Team

(2) Stage 2

1) Ta Khmao

a) Project Contents

Table 8.1.7 outlines the contents of the Ta Khmao Project. The Ta Khmao Project is currently underway with the support of JICA's Japanese Grant Aid with O&M Scheme.

Table 8.1.7 Contents of the Ta Khmao Project

Period	Stage	Project	Component	Contents
Immediate Period	Stage 2	Ta Khmao	Water Treatment Plant	Production Capacity: 30,000 m^3/day Construction of intake, transfer main, WTP, reservoir, distribution pumps
			Transmission Mains	Transmission mains (17km) and distribution mains (by PPWSA)
			Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

The implementation schedule of the Ta Khmao Project is shown in ***Table 8.1.8***. The planned production capacity is 30,000 m^3/day. Construction is scheduled to be completed in 2024.

Table 8.1.8 Implementation Schedule of the Ta Khmao Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Tendering	■									
Design & Build		■	■	■						

* Currently being implemented by Japanese Grant Aid Project
Source: JICA Data Collection Survey Team

8.1.3 Intermediate Period

Projects of the second period (the Intermediate Period) are intended to fill the gap between the water demand and production capacity in the existing PPWSA service area through the expansion of existing WTP schemes. Specifically, the projects planned in the Intermediate Period are:

(1) Stage 1

1) Phum Prek Phase III

a) Project Contents

Table 8.1.9 outlines the contents of the Phum Prek Phase III Project. Currently, the project is preparing to apply for JICA's Grant Aid with O&M assistance scheme. The planned production capacity is 45,000 m^3/day.

Table 8.1.9 Contents of the Phum Prek Phase III Project

Period	Stage	Project	Component	Contents
Intermediate Period	Stage 1	Phum Prek Phase III	Water Treatment Plant	Production Capacity: 45,000 m^3/day Construction of intake, transfer main (by PPWSA), WTP, reservoir, and distribution pump station
			Transmission Mains	Transmission mains (1km) and distribution mains (by PPWSA）
			Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.10 shows the implementation schedule plan for the Phum Prek Phase III Project. Construction is scheduled to be completed in 2026.

Table 8.1.10 Implementation Schedule of the Phum Prek Phase III Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
F/S	■									
Tendering		■								
Design & Build			■	■	■	■				

* Draft Project schedule assuming JICA Grant Aid Project has been applied
Source: JICA Data Collection Survey Team

(2) Stage 2

1) Bakheng Phase III

a) Project Contents

Due to the request of MISTI to the French Government mentioned in ***Section 8.1.1***, this survey proposes that the Bakheng Phase III Project will supply water to meet 2027 water demand.

Table 8.1.11 outlines the contents of the Bakheng Phase III Project. The planned production capacity is 195,000 m^3/day.

Table 8.1.11 Contents of the Bakheng Phase III Project

Period	Stage	Project	Component	Contents
Intermediate Period	Stage 2	Bakheng Phase III	Water Treatment Plant	Production Capacity: 195,000 m^3/ day Expansion of intake, transfer main(by PPWSA), WTP, reservoir, and distribution mains
			Transmission Mains	Transmission mains (66km) and distribution mains
			Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.12 shows the implementation schedule plan of the Bakheng Phase III Project. Construction is scheduled to be completed in 2027.

Table 8.1.12 Implementation Schedule of the Bakheng Phase III Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
F/S		■								
Consultant Selection			■							
Tendering				■						
Design & Build					■	■	■			

* Draft Project schedule assuming AfD Loan Aid
Source: JICA Data Collection Survey Team

2) Equipment Update of Chroy Changvar WTP

a) Project Contents

Table 8.1.13 outlines the contents of the Project for Equipment Update of Chroy Changvar WTP. The main component is the update of aged equipment.

Table 8.1.13 Contents of the Chroy Changvar Project

Period	Stage	Project	Component	Contents
Intermediate Period	Stage 2	Equipment Update of Chroy Changvar WTP	Water Treatment Plant	Production Capacity: 130,000 m^3/ day Expansion of intake, transfer main (by PPWSA), WTP, reservoir, and distribution mains
			Transmission Mains	Transmission mains (66km) and distribution mains
			Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.14 shows the implementation schedule plan of the Project for Equipment Update of Chroy Changvar WTP. Construction is scheduled to be completed in 2027.

Table 8.1.14 Implementation Schedule of the Chroy Changvar Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
F/S		■								
Consultant Selection			■							
Tendering				■						
Design & Build					■	■	■			

* Draft Project schedule assuming AfD Loan Aid
Source: JICA Data Collection Survey Team

8.1.4 Ultimate Period

The final period is the Ultimate Period. During this period, the PPSWA service area should cover the entire planned area through the expansion of existing WTPs, reconstruction of aged facilities at Phum Prek WTP, and development of new WTPs. Specifically, the projects planned in the Ultimate Period are:

(1) Stage 1

1) Nirodh Phase III

a) Project Contents

Table 8.1.15 outlines the contents of the Nirodh Phase III Project. The planned production capacity is 130,000 m^3/day.

Table 8.1.15 Contents of the Nirodh Phase III Project

Period	Stage	Project	Component	Contents
Ultimate Period	Stage 1	Nirodh Phase III	Water Treatment Plant	Production Capacity: 130,000 m^3/day Expansion of intake, transfer main (by PPWSA), WTP, reservoir, and distribution mains
			Transmission Mains	Transmission mains (25 km) and distribution mains
			Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.16 shows the implementation schedule plan of the Nirodh Phase III Project. Construction is scheduled to be completed in 2029.

Table 8.1.16 Implementation Schedule of the Nirodh Phase III Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
F/S		■								
Consultant Selection				■						
Tendering					■					
Design & Build						■	■	■	■	

* Draft Project schedule assuming JICA Loan Aid
Source: JICA Data Collection Survey Team

2) Koh Norea

a) Project Contents

Table 8.1.17 outlines the contents of the Koh Norea Project. The planned production capacity is 150,000 m^3/day.

Table 8.1.17 Contents of the Koh Norea Project

Period	Stage	Project	Component	Contents
Ultimate Period	Stage 1	Koh Norea	Water Treatment Plant	Production Capacity: 150,000 m^3/day Construction of intake, transfer main, WTP, reservoir, distribution pumps
			Transmission Mains	Transmission mains (33 km) and distribution mains
			Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.18 shows the implementation schedule plan of the Koh Norea Project. Construction is scheduled to be completed in 2029.

Table 8.1.18 Implementation Schedule of the Koh Norea Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
F/S										
Consultant Selection										
Tendering										
Design & Build										

* Draft Project schedule assuming JICA Loan Aid
Source: JICA Data Collection Survey Team

3) Reconstruction of Phum Prek Phase I

a) Project Contents

Table 8.1.19 outlines the contents of the Phum Prek Facility Renovation Phase I Project. In the Ultimate Period Stage 1, construction of new intake with a production capacity of 150,000 m^3/day and existing water treatment facilities with a production capacity of 100,000 m^3/day will be reconstructed as the first step of the renovation of the Phum Prek WTP.

Table 8.1.19 Contents of the Reconstruction of Phum Prek Phase I Project

Period	Stage	Project	Component	Contents
Ultimate Period	Stage 1	Reconstruction of Phum Prek Phase I	Water Treatment Plant	Construction of new intake facility and Reconstruction of existing water treatment facility: Production Capacity of 100,000 m^3/day including Comprehensive Monitoring and Management Center

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.20 shows the implementation schedule plan of the Reconstruction of Phum Prek Phase I Project. Construction is scheduled to be completed in 2029.

Table 8.1.20 Implementation Schedule of the Reconstruction of Phum Prek Phase I Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
F/S											
Consultant Selection											
Tendering											
Study & Design											
Reconstruction of Water Treatment Facility											

* Draft Project schedule assuming JICA Loan Aid
Source: JICA Data Collection Survey Team

(2) Stage 2

1) Ta Mouk Phase I

a) Project Contents

Table 8.1.21 outlines the contents of the Ta Mouk Phase I Project. The planned production capacity is 200,000 m^3/day.

Table 8.1.21 Contents of the Ta Mouk Phase I Project

Period	Stage	Project	Component	Contents
Ultimate Period	Stage 2	Ta Mouk Phase I	Water Treatment Plant	Production Capacity: 200,000 m^3/day Construction of intake, transfer main, WTP, reservoir, distribution pumps
			Transmission Mains	Transmission mains (35 km) and distribution mains
			Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.22 shows the implementation schedule plan of the Ta Mouk Phase I Project. Construction is scheduled to be completed in 2030.

Table 8.1.22 Implementation Schedule of the Ta Mouk Phase I Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
F/S		■								
Consultant Selection				■						
Tendering					■	■				
Design & Build							■	■	■	■

Source: JICA Data Collection Survey Team

2) Khsach Kanda

a) Project Contents

Table 8.1.23 outlines the contents of the Khsach Kanda Project. The planned production capacity is 100,000 m^3/day.

Table 8.1.23 Contents of the Khsach Kanda Project

Period	Stage	Project	Component	Contents
Ultimate Period	Stage 2	Khsach Kanda	Water Treatment Plant	Production Capacity: 200,000 m^3/day Construction of intake, transfer main, WTP,
			Transmission Mains	Transmission mains (10 km) and distribution mains
			Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.24 shows the implementation schedule plan of the Khsach Kanda Project. Construction is scheduled to be completed in 2030.

Table 8.1.24 Implementation Schedule of the Khsach Kanda Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
F/S					■					
Consultant Selection						■				
Tendering							■			
Design & Build								■	■	■

Source: JICA Data Collection Survey Team

3) Reconstruction of Phum Prek Phase I

a) Project Contents

Table 8.1.25 outlines the contents of the Phum Prek Phase 1 Facility Renovation Project. In the Ultimate Period Stage 2, a distribution reservoir with a capacity of 10,000 m^3 will be reconstructed as the second stage of the renovation of the Phum Prek WTP. Construction is scheduled to be completed in 2030.

Table 8.1.25 Contents of the Reconstruction of Phum Prek Phase I Project

Period	Stage	Project	Component	Contents
Ultimate Period	Stage 1	Reconstruction of Phum Prek Phase I	Water Treatment Plant	Production Capacity: 10,000 m^3 Renovation of reservoir

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.26 shows the implementation schedule plan of the Reconstruction of Phum Prek Phase I Project. Construction of distribution reservoir is scheduled to be completed in 2029.

Table 8.1.26 Implementation Schedule of the Reconstruction of Phum Prek Phase I Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
F/S		■									
Consultant Selection				■							
Tendering					■						
Study & Design						■					
Reconstruction of Service Reservoir									■		
Construction of Sludge Treatment Facility										■	■

* Draft Project schedule assuming JICA Loan Aid
Source: JICA Data Collection Survey Team

4) New Airport City

a) Project Contents

Table 8.1.27 outlines the contents of the New Airport City Project. The planned production capacity is 30,000 m^3/day. Construction is scheduled to be completed in 2030.

Table 8.1.27 Contents of the New Airport City Project

Period	Stage	Project	Component	Contents
Ultimate Period	Stage 2	New Airport City	Water Treatment Plant	Production Capacity: 30,000 m^3/day Construction of intake, transfer main, WTP,
			Transmission Mains	Transmission mains (10 km) and distribution mains
			Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.28 shows the implementation schedule plan of the New Airport City Project.

Table 8.1.28 Implementation Schedule of the New Airport City Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
F/S					■					
Consultant Selection						■				
Tendering							■			
Design & Build								■	■	■

Source: JICA Data Collection Survey Team

8.1.5 Completion After 2030

(1) Ta Mouk Phase II

a) Project Contents

Table 8.1.29 outlines the contents of the Ta Mouk Phase II Project. The planned production capacity is 200,000 m^3/day. Construction is scheduled to be completed in 2031.

Table 8.1.29 Contents of the Ta Mouk Phase II Project

Project	Component	Contents
Ta Mouk Phase II	Water Treatment Plant	Production Capacity: 200,000 m3/day Expansion of intake, transfer main, WTP, reservoir, distribution pumps
	Transmission Mains	Transmission mains (20 km) and distribution mains
	Distribution Mains	

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.30 shows the implementation schedule plan for the Ta Mouk Phase II Project. Construction will begin before 2030. Completion is planned in 2031.

Table 8.1.30 Implementation Schedule of the Ta Mouk Phase II Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
F/S			■								
Consultant Selection				■							
Tendering					■	■					
Design & Build										■	■

* Contract for Phase II construction will be made at the time of the Phase I contract. Phase II facility construction will begin during construction of Phase I facilities.

Source: JICA Data Collection Survey Team

(2) Reconstruction of Phum Prek Phase I

a) Project Contents

Table 8.1.31 outlines the contents of the Reconstruction of Phum Prek Phase I Project. This is the final stage of the renovation of the Phum Prek WTP. In the project, a new WTP will be constructed at the existing Phum Prek WTP site. Construction is scheduled to be completed in 2031.

Table 8.1.31 Contents of the Reconstruction of Phum Prek Phase II Project

Project	Component	Contents
Reconstruction of Phum Prek Phase I	Wastewater Treatment Facility at Phum Prek WTP	Production Capacity: 195,000 m^3/day Construction of WTP effluent treatment facility

Source: JICA Data Collection Survey Team

b) Implementation Schedule

Table 8.1.32 shows the implementation schedule plan of the Reconstruction of Phum Prek Phase I Project. Construction of WTP effluent treatment facility is scheduled to be completed in 2031.

Table 8.1.32 Implementation Schedule of the Reconstruction of Phum Prek Phase I Project

Items	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
F/S		■									
Consultant Selection				■							
Tendering					■						
Study & Design						■					
Reconstruction of Water Treatment Facility							■	■			
Reconstruction of Service Reservoir									■		
Construction of Sludge Treatment Facility										■	■

* Draft Project schedule assuming JICA Loan Aid
Source: JICA Data Collection Survey Team

8.2 NEXT PHNOM PENH WATER SUPPLY MASTER PLAN (4th Master Plan)

The target year of the Third Master Plan (M/P2017) is 2030. The Fourth Master Plan should be created before this year to avoid periods where master planning does not exist. The Fourth Master Plan should be created as near the end of the Third Master Plan to reflect the latest conditions.

It is expected that many development goals such as national plans and urban development plans will be set to 2050, which is the turning point of the 21st century. The target year of the 4th Master Plan is also proposed to be set to 2050. This makes the planning period of the Fourth Master Plan from 2030 until 2050, a period of 20 years.

Through discussions with PPWSA, it was confirmed that higher level plans and goals such as the National Development Plan (except for the city development plan for 2035 in the "White Book on Development and Planning of Phnom Penh" planned by Phnom Penh City Centre as shown ***Figure 8.2.1*** below and "The Project for Sewerage System Development in the Phnom Penh Capital City" implemented by JICA) are not activated yet.

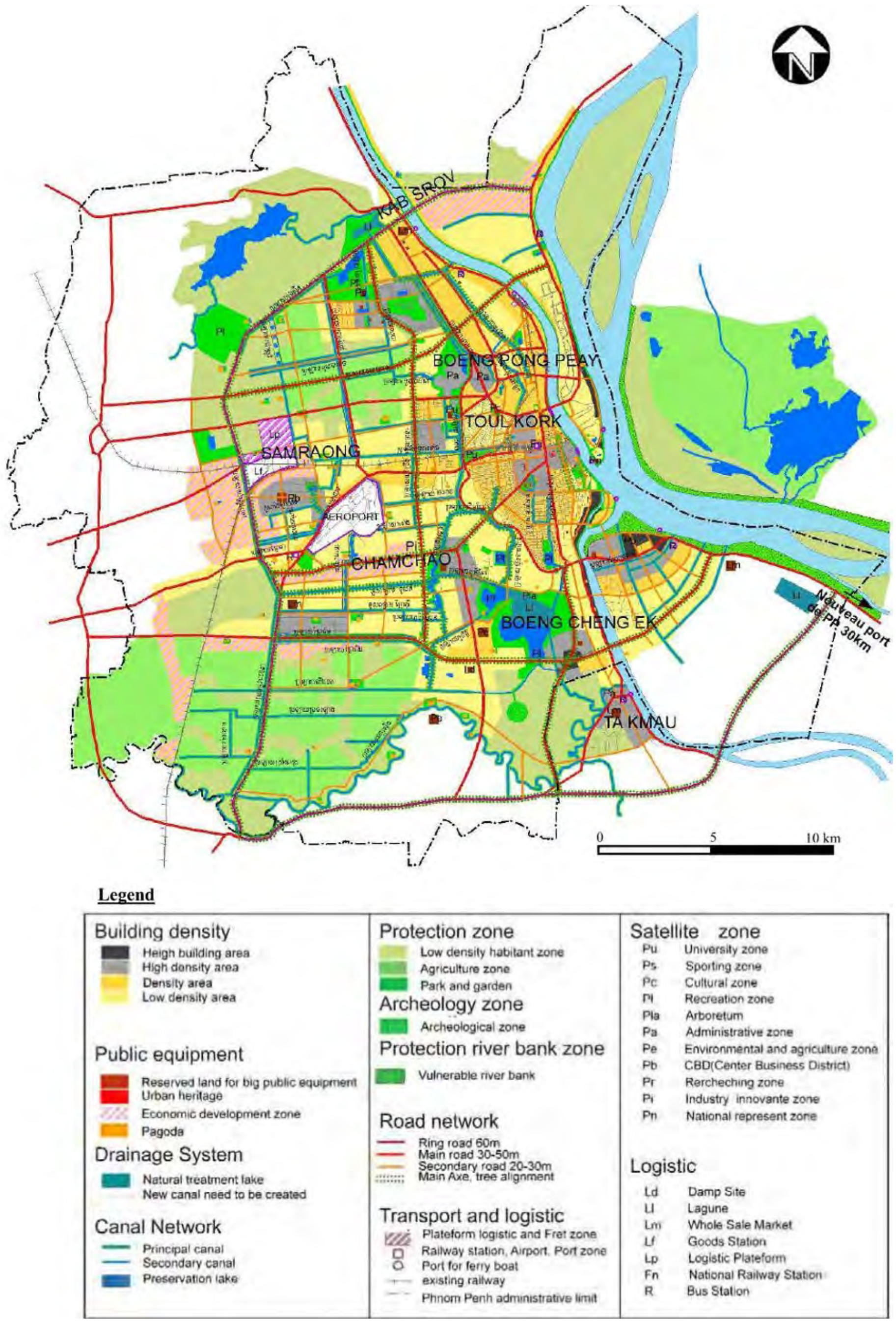


Figure 8.2.1 Phnom Pench City Development Plan for 2035

Source: White Book on Development and Planning of Phnom Penh, Phnom Penh City Centre

The proposed implementation plan of the Fourth M/P is summarized as follows.

Table 8.2.1 Summary of the Fourth Master Plan

	Contents
Implementation Agency	JICA
Counterpart	PPWSA
Implementation Period	2027 to 2029
Contents of the Study	To review the previous water supply master plan (to be updated in this study): - to review water demand forecast compared with actual water supply condition, - to survey water resources condition, - to survey condition of existing water supply facilities, - to survey city development condition, - to survey financial condition of PPWSA, and - to survey issues in the water supply system and the management To generate next water supply master plan (up to 2050): - to study related law and regulations,

	- to study water resources availability, - to study future city development plan, - to forecast the water demand for 2050, - to make facility development plan, - to make staged development plan, - to study on human resources development and institutional improvement, - to consider the response and mitigation measures against climate change - to estimate the cost, and - to carry out financial analysis

Source: JICA Data Collection Survey Team

It is not uncommon for urban development and water demand patterns to deviate significantly from forecasts in a short period of time. The Fourth Master Plan should be reviewed every five years and modified to reflect the latest situation of the time. It will be necessary to develop the human resources of PPWSA so that it can regularly check the actual city development situations, apply those findings to formulate, and update an optimal water supply plan according to the latest needs.

The M/P2029 is proposed be reviewed and updated every five years: in 2034, 2039, 2044, and finally in 2049. The 2049 review should generate the next plan, the Phnom Penh Water Supply Master Plan for 2075 (Fifth Phnom Penh Water Supply Master Plan). In addition, it is proposed that the Sixth Phnom Penh Water Supply Master Plan sets 2100 as the target date.

PPWSA will have rich and varied experiences in the water supply sector and will have excellent human resources in the future. The review and update of MP/2029 and preparation of the Fifth and Sixth Phnom Penh Water Supply Master Plan are expected to be implemented mainly by PPWSA itself.

The second review of the Fourth Master Plan (2035) and review of water supply plan and regular reviews of the plans in during the Fifth Master Plan and onwards should be carried out mainly by PPWSA staff who will have gain valuable planning and reviewing knowledge and experience through the implementation of the action plans of this current master plan.

CHAPTER 9 INSTITUTIONAL DEVELOPMENT

9.1 CURRENT INSTITUTIONAL SITUATIONS

Toward the year 2030, PPWSA needs to develop the institutional aspects as well in order to ensure the implementation of the facility expansion projects described in the previous chapters. In order to operate and manage the expanding facilities properly, and to continuously provide services, it is also necessary to develop the organizational aspects. In this chapter, the current status of PPWSA's organizational management is first reviewed and the policy for development is defined. Then, focusing on the 10 areas that were assessed to require strengthening in the Third Master Plan (M/P 2017), the current status and issues are identified by area. Based on this, targets, development policies, and monitoring indicators are set as actions for 2030 and development measures are presented along with implementation schedules.

In this chapter, the development of the institutional aspects will be discussed by department. The organizational chart of the PPWSA is shown in the figure below. The organizational structure of PPWSA consists of six departments and offices directly under the Director General that are responsible for institutional control and the management of the Board of Directors.

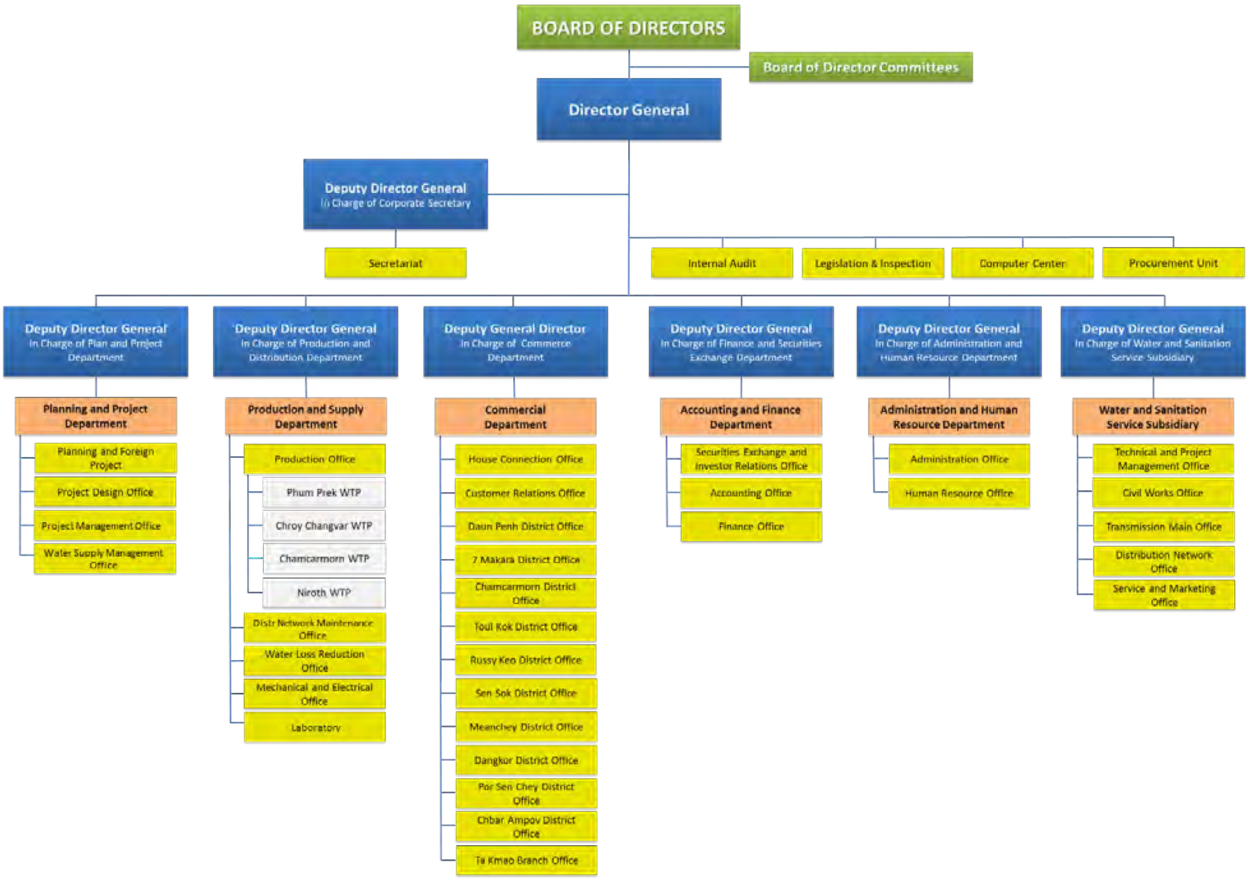


Figure 9.1.1 Organization Chart of PPWSA
Source: JICA Data Collection Survey Team based on information from PPWSA

9.1.1 SWOT Analysis

The results of the SWOT analysis of the factors influencing the business operation of PPWSA are shown in ***Table 9.1.1***. The descriptions *in italics* in the table indicate the situation that continues from the time of the Third Master Plan (M/P 2017) study.

Table 9.1.1 Results of SWOT analysis on factors impacting business operations

Results of SWOT Analysis on Factors Impacting Business Operations		
Internal Factors	**Strengths**	**Weaknesses**
Management	*- Capable and experienced leadership and management team in most departments*	*- Very centralized and partitioned organization with limited delegation of authority.*

Results of SWOT Analysis on Factors Impacting Business Operations		
Internal Factors	**Strengths**	**Weaknesses**
	- Plan-driven approach *- Clear accountability for results and standards of performance* *- Transparency is important in the PPWSA "culture"*	*- Organization dependent on some key elements with high quality training from the Soviet period that will retire in the next several years* - Need for appropriate management of the number of staff to cope with the rapid expansion of services - Unclear long-term business goals and vision
Water demand& production	*- Relatively new WTPs* *- Improvement of O&M techniques with the start of new WTP* - O&M in accordance with SOPs	- *O&M still needs to be improved* *- Insufficient production capacity for current demand* - Difficulties in maintenance tasks that affect the amount of water produced *- Connections are installed faster than water production capacity increases, so it is difficult to know the demand and plan accordingly* - Increase in problems due to aging equipment (PPK1, CCW1) *- Lack of emergency procedures*
Water distribution	*- New facilities.* *- 100 % metered connections*	*_ Data management and analysis can be improved* *_ O&M still needs to be improved* - Complicated water control due to expansion of water supply area and increase in number of WTPs - *Lack of emergency procedures*
Water loss	*- Policies and loss monitoring program effective* *- Data management and telemetering systems are relatively new.* - Distribution network based on DMA	- Deterioration of equipment including sensors - Open DMA for water operation to meet demand
Commercial	*- Good water quality and pressure in most of the network* *- Service available 24-hours.* *- "Water for all" policy allows poor households connection* *- Proactive communication policy (Website, Facebook…)* *- Almost 100% billing and collection ratio* - Increased efficiency and accuracy by introducing electronic device for billing - Revision of tariff (2017, 2020)	- Reduced economies of scale due to expansion into suburban areas - *Still no formal customer service centre implemented* *- "Water for all" policy has a negative impact on average water tariff* - Need for staged tariff revision for implementation of development projects
Finance	*- High performance department with computerized tools and international procedures*	- *Lack of long-term planning* - Need to secure financing for successive expansion projects - Financial burden of operating and contributing to other waterworks
Human resources	*- High sense of ownership by staff* *- Highly motivated staff* *- Performance-based incentive and reward systems in place*	-Need to strengthen technology transfer and cultural inheritance for increased young staff. - Strategic development of specialized staff who can cope with the introduction of new technologies - Limited opportunities for young staff to satisfy their desire for growth and recognition as SOP-based routine tasks increase.
External Factors	**Opportunities**	**Threats**
National/urban economy	*- Strong urban growth rate*	*- Downturn in the economy will have adverse effects on PPWSA (directly) and its consumers ability to pay* - Urban development projects have led to rising land prices, unexpectedly high water demand in central areas, and increased incidents of broken water pipes.
Government policy	*- Monopoly of service (except some of the 20 new communes)* - Policy to transfer water supply in suburban areas to PPWSA - Expansion of possibility of tariff revision	*- Increased political interference encroaching on PPWSA's independence* - Application of wastewater regulations to discharges from WTPs
Relations with other water waterworks in Cambodia	*- Opportunities for additional markets (network construction, trenchless works…)* *- Opportunities to sell training services to other water operators*	- Informal use of PPWSA for special missions in other cities places a burden on PPWSA resources
Access to external	*- Strong support from international financial*	_ Non-sovereign loans proved successful but are

Results of SWOT Analysis on Factors Impacting Business Operations		
Internal Factors	**Strengths**	**Weaknesses**
finance and technical assistance	*institutions* *- Continued good reputation of PPWSA* *- IPO provided a new way to access capitals*	now prohibited by the Government
Consumers	*- High willingness-to-connect and willingness-to-pay* *- Overall satisfaction especially regarding water tariffs*	*- Some dissatisfaction from customers experiencing low pressure* - Lack of customers knowledge: anew social survey would be necessary - Rapid demand increasing in the central and suburban areas
Electricity	*- Good service from power supply company* - Various development technologies that can be applied to save energy, especially for pumps, and optimize water control.	*- Critical cost driver in PPWSA operating margin*
Water resources	*- Adequate volume of raw water at sources*	*- Slow deterioration of raw water quality must be monitored more closely* *- City development occurs further and further away from eastern resources* *- Limited alternative resources available* - Decreasing trend of river water level at existing raw water intake points (CCW, NRT) - Development of landfill at existing intake points (Nirodh)

*The descriptions in italics in the table indicate the status that continues from the time of the M/P (2017).
Source: JICA Data Collection Survey Team

9.1.2 Maturity Assessment

The Third Master Plan (M/P 2017) assesses the maturity level of PPWSA in terms of the degree of “resources, tools and procedures mobilized to perform” each activity. The assessment uses a 6-point scale (level 3 is international standard, and level 6 is international excellence). PPWSA's overall score of 3.3 was assessed as “excellent”.

Based on the maturity assessment in 2017, this study identified areas where major developments were observed from 2017 to 2021 in terms of “resources, tools and procedures mobilized to carry”.

A matrix showing the maturity scores in 2017 and the areas of development and development by 2021 is shown ***Table 9.1.2*** below. For progress and details on improvements and developments up to 2021, see ***Section 9.3.***

Table 9.1.2 Scores of Maturity (2017) and Major Improved Field Observed in2021

Areas	Fields, activities	Maturity Score by the Third Master Plan (M/P 2017)* (Scale of 1 to 6, int’l average is 3.0)	Major Developed Fields Observed in 2021
Drinking water	WTP & Pumping	3.5	★
	Laboratory & Water Quality	2.7	★
	Transmission Network Management	3.2	
	Storage Tanks Management	3.0	
	Distribution Network Management	3.2	★
	Leak Detection	4.1	
	Electromechanical Maintenance	2.3	
	Network Maintenance & Site Works	3.2	★
	Water Network Mapping	3.8	★
Customer service	Customer Database Management	4.9	
	Meter Management	4.1	
	Meter Reading	3.5	★★
	Invoicing / Billing	4.1	★★
	Payments / Collection Invoicing / Billing	4.5	★★
	Customer Contact	2.2	★
	New connections	3.8	
Support	Accounting / Controlling	4.3	

	Investment management	4.6	
	Stakeholder Relation	3.1	
	Human Resources / Learning	2.6	
	Emergency Response & Management	0.6	
	Information Technology	3.6	
	Real-Time Monitoring	2.9	★
	Equipment renewal management	1.7	★
transversal	Non-Revenue Water	3.0	
	Energy Management	2.5	on-going
	Resource Management	2.7	

Source: Assessment items and scores for 2017 are from the M/P (2017), Assessment in 2021 conducted by JICA Data Collection Survey Team based on interviews with PPWSA.

9.2 DIRECTIONS FOR DEVELOPMENT

In order to implement each project based on the facility expansion plan presented in the previous chapters, and to continuously operate the facilities and provide services at a high level, the following sections describes the issues that need to be developed in the future based on the current situation, and specifies targets and actions for development in each field. The actions to be taken for the development are not only those with high priority for implementation by 2030, but also those that should be considered from a medium-term perspective. The actions for development are shown in three periods: Immediate Period (2021-2024), Intermediate Period (2025-2027), and Ultimate Period (2028-2030).

Within the PPWSA, business is mainly managed on a departmental basis, and when business plans and proposals cross over to multiple departments, the responsibilities of implementation are likely to be unclear. Therefore, in the following section, development actions are presented corresponding to the responsibilities of each department, and actions concerning the organization as a whole are shown at the end. The items of institutional development are outlined as shown in ***Table 9.2.1.***

Table 9.2.1 Items of Institutional Development

Section Number and Responsible Departments	Development Items
9-4-1 Planning and Project	Strengthening of engineering office
9-4-2 Production and Distribution	Water loss management Water quality management and monitoring, water safety plan Distribution control and energy efficiency Maintenance, asset management Data collection for renewal
9-4-3 Commercial	Customer relation and PR
9-4-4 Finance and Accounting	Water tariff
9-4-5 Administration and Human Resources	Management of staff number Huma resource management
9-4-6 Overall organization	Structure of top management Risk management and response Contribution for other waterworks, and water supply sector

Source: JICA Data Collection Survey Team

9.3 MAJOR MEASURES

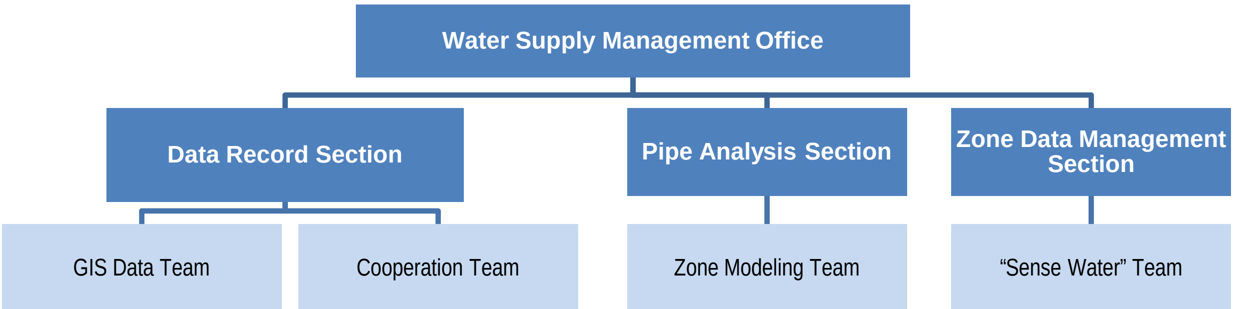
9.3.1 Planning and Project

(1) Strengthening of Engineering Office

1) Current Situation

Following the recommendations of the Third Master Plan (M/P 2017), a new Water Supply Management Office has been established in the Planning & Project Department. The structure and the major duties of each of the sub offices are shown in ***Figure 9.3.1***. The main tasks of the office are as follows:

- To manage GIS data and plan water distribution network based on GIS data.
- To monitor water pressure and flow data collected by SCADA of WTPs, meters installed elevated tanks and DMAs, and confirm the minimum night flow using Sense Water (at the inlets of all DMAs). Based on the results, when the minimum night flow exceeds the threshold, Water Loss Office is contacted. When any problem is found with the sensor, Electrical & Mechanical Office is contacted for inspection and maintenance.



KIS Admin managing all GIS system Inputting data of pipeline and attaching As-Built drawing into GIS system. Correcting the drawing of TM and Distribution pipeline.	KIS Admin managing all GIS system Checking, monitoring, and reporting KIS trouble every time. Revising existing data in KIS program.	Studying on zone pipeline. Cooperating and revising DMA with relevant offices. Checking Boundary Valves in each zone. Revising customer data of each DMA.	Management of Sense Water Admin. Checking and monitoring properly the data in Sense Water. Analysing minimum night flow in Sense Water system. Analysing water balance in Sense Water program.

Figure 9.3.1 Structure and Major Duties of Water Supply Management Office
Source: JICA Data Collection Survey Team based on the information provided by PPWSA

With the establishment of this office, the accumulation and analysis of engineering and daily operation and maintenance data in the area of water transmission and distribution has been consolidated. There are plans to introduce a hydraulic model system based on water demand forecasting in the future, and the strengthening of this office has made it possible to conduct comprehensive hydraulic analysis from water intake to water taps internally.

After reorganization, one remaining issue is access to GIS data. Currently, the GIS Section, which is in charge of GIS data management, is under tge Planning and Project Department. But since GIS information is frequently referred to in maintenance work, it needs to be easily accessible by the Production and Distribution Department which is in charge of these tasks. Currently, the data can be accessed and utilized in a timely manner for operations such as leak detection and repair and maintenance of electrical facilities in Production and Distribution Department, but access to GIS and information sharing in emergencies such as large diameter pipe breakage is an issue.

The section is also responsible for the area of water transmission and distribution control. The Planning and Project Department manages the data transmitted from SCADA related to water transmission and distribution, such as flow rate and water pressure at each DMA, water treatment plant, and elevated tank. The Production and Distribution Department manages the record books and other information related to operation and on-site maintenance. While data is recorded and stored accurately in both departments, neither have an effective system to evaluate and analyse the data from a mid/long-term perspective. This is a typical situation throughout PPWSA as a whole. Although daily operations are recorded and stored based on SOPs, generally, systems and human resources are insufficient to analyse those data and utilize them to improve operations.

Up to now, when new technologies and materials/equipment were introduced, their validities have been examined on a project-by-project basis. A system for evaluating the validity of the introduced technologies has not been established. The system needs to be strengthened so that the O&M data can be verified, compared the actual benefit with the estimation made before the implementation, and the technologies introduced be evaluated and used for evaluation to introduce new technologies. In particular, the real-time monitoring of water quality has been facing some challenges such as short lifecycle of the sensors, rapid deterioration of accuracy compared to water pressure and flow rate, difficulty of calibration, and high cost of spare parts. It is necessary to verify the cost effectiveness over the longer term when expanding the monitoring system. In addition, since it has been determined that “Law on Environmental Protection and Natural Resources Management” and regulation on “Water Pollution Control” are to be applied to discharge from water treatment plants to be constructed hereafter, it is expected that the technological information on discharge and sludge treatment will also need to be collected and studied.

2) Measures for development toward 2030

a. Objectives

Strengthen the Water Supply Management Office to oversee engineering, accumulate technological know-how and establish it as an office in charge of technical evaluation. The office should establish a system to examine longer-term data evaluation, appropriateness of technology, and investment effectiveness. By promoting technical verification activities in cooperation with relevant departments, the office will aim to develop the capacity of offices related to operation in parallel.

b. Directions

Extension of the Water Supply Management Office: The Office will be expanded to provide a system for mid- to long-term analysis, evaluation of the technical validity of projects, and planning of the next project based on operation and maintenance management data.

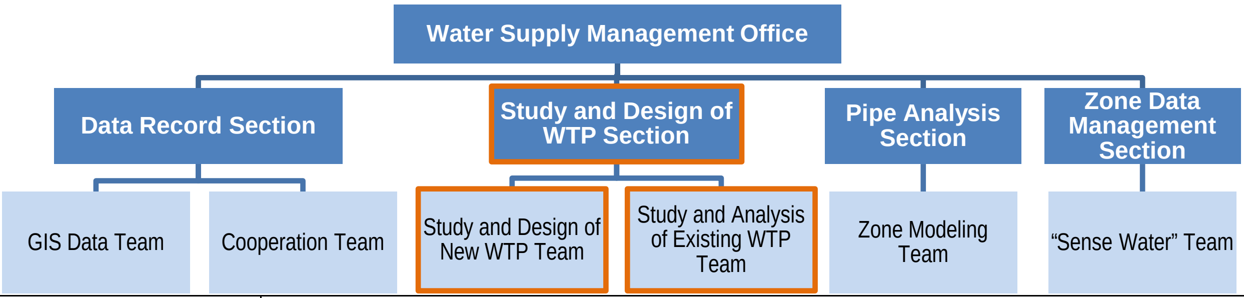
Specifically, the Engineering Office will play a central role in accumulating engineering know-how and technological R&D by setting up Taskforce Teams with related sections/departments to conduct technical surveys, focusing on the technical analysis items shown below.

[Major Technical Analysis Items]

- ✓ Management of production volume and energy saving: Detailed in Section **9.3.2(3)**
- ✓ Water treatment and quality management: Examine whether the existing treatment technologies are the most appropriate to treat its raw water in terms of operation costs of each WTP, analyse and compare unit costs of WTP, examine WTP assigned by demand area.
- ✓ Drainage and sludge treatment: Technologies required in the future. Consideration of technologies to be introduced to meet discharge water standards, and verification of their effectiveness and efficiency after introduction.
- ✓ Water transmission and distribution: Strengthen hydraulic analysis and modelling in water operations. Conduct systematic survey and GIS mapping of points where water pressure and quality is problematic.
- ✓ Asset management: Verify the long-term cost-effectiveness of automatic measurement systems (especially water quality monitoring). Evaluate the performance of the water transmission and distribution network and reflect its results to improve the existing network using hydraulic modelling.
- ✓ Energy conservation: Analysis and optimization of electricity consumption at WTPs and major facilities (including coordination with EDC).

The Planning and Project Department is in the process of reinforcing its function of supervising technology. In particular, it is in the process of launching the Study and Design of WTP Section, which will be in charge of technical studies in areas related to raw water quality, water treatment technologies, and facilities of treatment. ***Figure 9.3.2*** below shows the organization and main tasks of the new section, highlighted in red.

With the establishment of this department, a section responsible for technical studies on water quality management will be identified. Under the Water Supply Management Office, along with the Pipe Analysis Section (design of pipelines) and the Zone Data Management Section (transmission and distribution water management), there will be dedicated sections for the major technical analysis items mentioned above. The capacity of the Water Supply Management Office as a whole are recommended to be strengthened so that these sections can be responsible for the technical studies mentioned above.



Study and Design of New WTP Team	▪ Study hydraulic calculation from intake to WTP ▪ Study the water treatment technologies ▪ Design of intake pump and WTP, backwash and other facilities ▪ Design and calculation of the size of treatment facilities and clear water reservoirs ▪ Analyse the raw water quality to decide the water treatment process ▪ Collaborate on the study of electrical and mechanical work
Study and Analysis of Existing WTP Team	▪ Study and improve the operation of raw water pumps, WTPs, backwash and other facilities ▪ Study the water quality change and propose the solution ▪ Study the water level and flow of source water in the climate change condition ▪ Analyse the raw water quality to decide water treatment process in accordance with the circumstance and new technologies

Figure 9.3.2 New Structure and Major Duties of Water Supply Management Office
Source: JICA Data Collection Survey Team based on the information provided by PPWSA

c. Indicators to monitor the progress

- ✓ Establishment of the Study and Design WTP Section (Study and WQ to adapt/existing WTP to improve/suggest new technologies for WTPs.)
- ✓ The number of studies which evaluate cost-benefit or appropriateness of the technologies applied/to be applied.

d. Actions for development

Table 9.3.1 Actions for Development (Strengthening of Engineering Office)

No.	Actions	2021-2024	2025-2027	2028-2030
1a.	Define the duties and responsibilities of the Study and Design WTP Section in consultation with the Production & Distribution Department.	- - →	(Continue	
1b.	Identify the necessary personnel required for the Engineering Office based on its job description.	→		
1c.	Set up Engineering Office and continuously strengthen the capacity of the staff. (Basic knowledge of data validation and analysis, statistics, project evaluation, financial evaluation, etc., and practical exercises using past case studies, etc.)	————	————	———→
2.	Appoint a team / staff in charge of "technology intelligence" and innovation through monitoring of the tools and techniques available on the market and applied in other waterworks, and adaptation of these in PPWSA	- - - - (Continue)	- - - -	- - →
3a.	For the major technical analysis items listed above, Taskforce Teams will be established for each subject with the Production & Distribution Department and other related departments to confirm the priority and necessity of the research.	→		
3b.	For high-priority items, the Engineering Office works with each Taskforce Team to analyse and evaluate the data, and study the appropriateness of the applied technology and its applicability to future projects.		————	———→
4.	Discuss GIS-related tasks with the Production & Distribution Department, clearly organize the tasks of daily O&M data management and long-term data accumulation, analysis, and utilization, and review the work responsibilities.		→	
5.	Clarify the operations that require emergency response (e.g., response to large-diameter pipe bursts, WQ problems, shut-down of WTP) related to the managed data with the Production & Distribution Department, define the procedures as SOPs, and conduct a simulated drill.	→		

Source: JICA Data Collection Survey Team

(2) Other recommendations

Development and utilization of IT: Along with the expansion of facilities and services, further utilization of IT will be considered. Gather information on operational examples of the use of IT in other water utilities and other sectors, and work closely with each department to improve the efficiency of operations.

- ✓ Remote control and real-time monitoring of operations related to WTP, transmission, and distribution
- ✓ Integration and efficiency enhancement of business operation data acquisition and management
- ✓ Efficient information sharing between departments at head office and between each site
- ✓ Increased operational efficiency by introducing automation of manual tasks: customer service management, procurement management, staff attendance management, etc.

Integration and utilization of GIS data: PPWSA as a whole should integrate GIS data so that each department can access the data in a timely manner. In addition to this, it is advisable to strengthen the management of data related to the project (CAD, GIS, drawings, reports, etc.) and establish a system that allows for daily reference to the data by Production and Distribution Department, Water and Sanitation Service Subsidiary, and Commercial Department.

9.3.2 Production and Distribution

(1) Water Loss Management

1) Current Situation

Currently, the biggest challenge facing PPWSA is the shortage of water supply relative to demand, so dealing with water loss is a particularly important organizational issue. Non-revenue water management is also considered important from a financial point of view, and it is a critical issue to control the non-revenue water ratio below 10% in order to ensure the profitability of the project. ***Figure 9.3.3*** below shows the non-revenue water ratio in recent years.

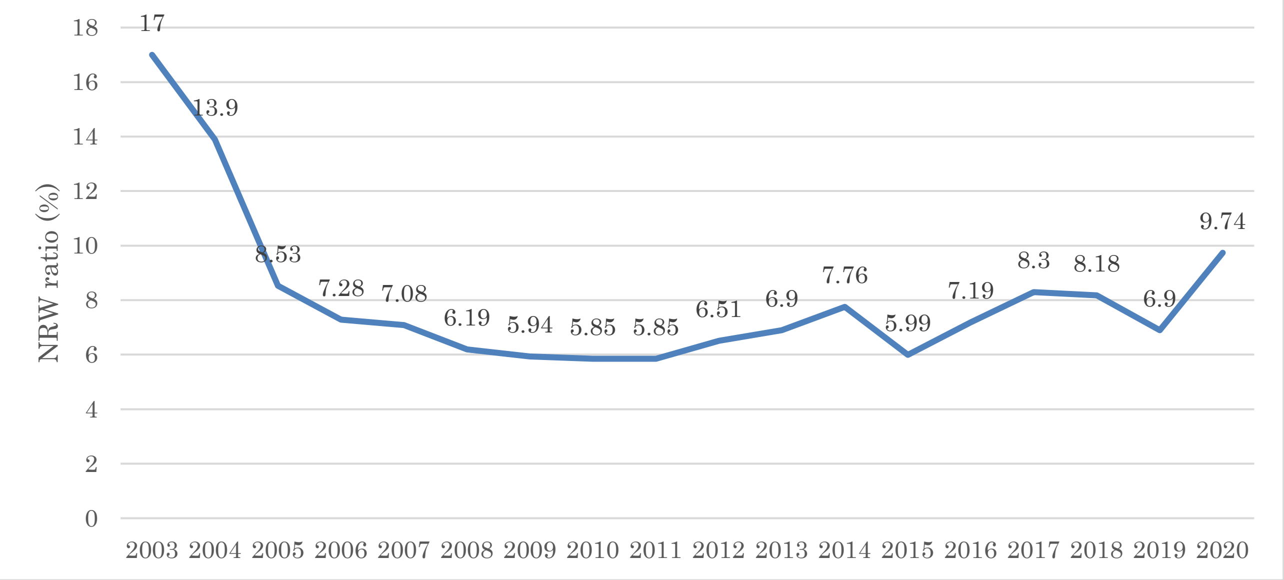


Figure 9.3.3 NRW Ratio (2003-2020)

Source： PPWSA (Annual report)

In PPWSA, Non-revenue water measures have already been implemented at a very high degree, and the achievement of keeping non-revenue water low for many years can be regarded as a high performance in international standards. The main NRW activities currently being implemented by PPWSA are listed below.

- ✓ Appling prefabricated house connection meter
- ✓ Replacement of old pipes
- ✓ Checking the accuracy of customer meters every 11 years
- ✓ Selection of appropriate size meters for each user according to their demand volume
- ✓ Leak detection and repair
- ✓ Public relations for citizens to report water leakage through SNS.

- On the other hand, pipes laid after the civil war are gradually aging, and some pipes are now over 20 years old.
- After the restructuring of DMAs in 2017, 118 DMAs have been set up to date, but in order to ease the shortage of water supply, the valves separating the DMAs are being opened to send water, which makes non-revenue water management difficult.
- The water pressure in the supply area has been monitored by potable flow meters three times a year. However, it is not possible to control the water pressure and water volume in the entire water supply area. In addition, there have been a series of accidents causing damages to water pipes in various projects associated with development and expansion in the suburbs of the city, making it difficult to reduce the non-revenue water ratio.
- After the Bakken Water Treatment Plant begins operation, it is expected that as the supply volume increases and the DMA becomes operational, not only will the detection of water losses become easier, but also the water pressure control will become easier as the transmission and distribution network is reorganized systematically.

2) Measures for Development Toward 2030

a. Objectives

Prioritize efficient water loss activities in order to control NRW ratio less than 10%.

b. Indicator

NRW ratio; monitoring that it is controlled to less than 10%.

c. Actions

In addition to continuing the current water loss measures, it is necessary to proceed with the expansion of preventive measures due to the increase in the number of aging pipes and the assumed unstable water pressure caused by changes in water operations.

Table 9.3.2 Actions for Development (Water Loss Management)

	Actions	2021-2024	2025-2027	2028-2030
Preventive measures	Implement water distribution management responding to pressure in entire supply area	→	→	→
	Provide clear instruction for the case of the pipe breaks	- - - (Continue	- - -	- - →
	Assess the impact of ageing on meters by studying the average consumption vs. age of meter, in order to optimize meter replacement frequency (11 years is verified?)		→	→
	Carry out random sampling and accuracy check of meters	→	→	
	Continue to implement zoning (monitoring water pressure and water flow at the inlets of DMA)	→	→	
Leakage management	Conduct regular inspection of separation of DMA by zero-pressure test.		→	→
	Set up a special inspection program for the transmission network		→	→
	Conduct drills for emergency responses (main pipe burst etc.) especially for cooperation with Planning Dept.	→	→	→
	Progressively try new leak detection techniques (acoustic correlators in the most sensitive zones, etc.)	→	→	
Water loss monitoring	Tight monitoring and recording of water losses in water treatment plant		→	→

Source: JICA Data Collection Survey Team

(2) Water Quality Management and Monitoring, and Water Safety Plan

1) Current Situation

Overall, water quality analysis in PPWSA has been strengthened by establishing SOPs in accordance with the National Drinking Water Quality Standards of Cambodia (hereinafter referred to as “NDWQS”) and obtaining ISO certification. However, in the area of water quality management, which includes evaluation of analytical data, analysis of trends using the data, and studies and proposals for development of water treatment, the section in charge has not been defined. This needs to be clarified and its capacity strengthened in the future.

a. Organizational Structure

The Laboratory is responsible for water quality analysis and has a total of 11 chemical staff in laboratories located in the NRT, PPK, CCW, and CKM water treatment plants.

The Laboratory's duties include conducting daily water quality analysis, compiling the results, and submitting the results to the Production Office in monthly and annual reports. The Laboratory is also responsible for the water quality analysis of the two water treatment plants of provincial waterworks operated by PPWSA.

Due to the limited number of staff, they are occupied with routine analysis work and are not able to be involved in water quality management, which includes, for example, advice on development of operation and maintenance of WTPs based on the results of water quality analysis, examination of emergency response, examination of the validity of monitoring parameters, and analysis of changes in water quality in the distribution area. Currently, the section in charge of these tasks is not clearly defined.

b. Monitoring Items

The Laboratory analyses 38 items; the NDWQS sets 26 monitoring items for treated water, of which the five items not measured by PPWSA are barium, cadmium, lead, mercury, and taste/odor. Since 2018, one sample from the outlet of the water treatment plant is being annually sent to Singapore for analysis of 116 items (including all items in the water quality standards). The analysis results all meet the NDWQS and are used as evidence to demonstrate the safety of water to the customers.

For the above-mentioned heavy metals not yet measured internally by PPWSA, the analysis method stipulated in the NDWQS requires that an atomic absorption spectrophotometer (hereinafter referred to as "AAS") be used. The introduction of an AAS instrument will enable PPWSA to analyse the four heavy metals (barium, cadmium, lead, and mercury) which are currently unmeasured. It can also be used to measure iron and manganese, which are currently being measured using different methods.

c. Accuracy of Analysis

Procedures for all analytical items are defined in SOPs and are analysed in accordance with them. In order to demonstrate the reliability of analytical results to customers and third parties, ISO 17025 (competence of testing and calibration laboratories) certification procedures were introduced, and in December 2020, five parameters at NRT's laboratory (pH, turbidity, manganese, conductivity, nitrite) were certified. In working to obtain certification for other laboratories and other parameter in the future, the laboratories will need to scrutinize the description of SOPs and analysis procedures especially for the items that were not accepted by ISO accreditation. Analytical instruments are being transported to Hong Kong (and Vietnam in 2020) for maintenance, which is scheduled to be completed in 2022.

d. Monitoring Points

The laboratory at each WTP analyses raw water, settled water, filtered water, and treated water. In addition, pH, turbidity, and residual chlorine are monitored in real time using the SCADA system at each WTP, but the accuracy is not satisfactory due to the frequent need for equipment calibration and the rapid deterioration of the sensors. In the future, monitoring of water quality at each DMA inlet point is being considered.

e. Water Quality Management System

PPWSA has developed a water safety plan, the implementation of which is consistent with the NDWQS. In the plan, hazards assessment, response methods, emergency response plans, etc. are implemented and formulated, which is useful for the operation of water supply, especially for water treatment. The plan will be more effective if it is reviewed periodically based on operational results.

f. Overall Assessment and Way Forward

The developments in water quality analysis items, monitoring points, frequency, etc. are being discussed within PPWSA. Strengthening of laboratories needs to be progressed, including development of specialists, maintenance of equipment and instruments, and management of reagents. Considering that the purpose of water quality analysis is to confirm the safety of water and to use the results to improve water quality, it is expected that, in parallel with the expansion of water quality analysis capacity, the areas of data analysis and evaluation, and the study of measures for water quality management will be strengthened in order to maximize the use of the analysis results. Since the laboratories are in charge of determining the amount of various chemicals to be injected in water treatment and monitoring residual chlorine, it is recommended that the laboratories take the initiative in analysing the data from the water quality analysis results and manage the water quality in cooperation with the water treatment plants and the departments in charge of water transmission and distribution.

As the number of water treatment plants increases and the water transmission system becomes more complex, the monitoring of water quality in the water supply area will become more important. Currently, the introduction of automatic/real-time water quality monitoring using SCADA systems, etc., is being considered. In the future, it is advisable to consider building a central monitoring control room for real-time water quality monitoring, along with water distribution monitoring, in the PPWSA headquarters. However, as has been a problem with existing water quality monitoring systems in WTPs, water quality meters require more frequent calibration than other automatic meters, the life of sensors is shorter, and replacement parts are more expensive. It is advisable to consider the cost-benefit of the entire system when introducing it.

2) Measures for Development Toward 2030

a. Objectives

Set water quality management roles and goals, review water quality monitoring methods and systems, and use analytical results to predict changes in raw water quality and improve treated water quality.

b. Directions

Capacity development of water quality analysis

- To improve the accuracy and precision of water quality analysis by adopting the analysis methods specified in the NDWQS. (Internal precision control).
- Strengthen laboratories to be able to analyse all parameters specified in the NDWQS.

Strengthening of water quality management capabilities by utilizing analysis results

- Clarify the section in charge of water quality management.
- Share the roles and objectives of water quality management among relevant departments.
- For the accumulation and utilization of analysis data, clarify the responsibilities of related sections and the workflow including a clear decision-making process.
- Update the water safety plan and ensure its implementation to achieve comprehensive water quality management.
- Strengthen capacity for data verification and analysis of water quality monitoring results, reflection in water treatment, and consideration of countermeasures.
- Strengthen the monitoring system for water source quality.

Study the future of water quality management

- Establishing a water quality management system will improve not only the trust of customers but also the credibility of the organization by ensuring current and future water safety and establishing emergency response. In addition, by having the best laboratory in Cambodia for water quality, it is expected that PPWSA will be able to obtain revenue from contracted water quality analysis services from outside and will also contribute to the development of domestic and international water supply utilities through contracted water quality analysis and training services.
- Consideration of measures to achieve this goal: Consideration of strengthening the real-time monitoring of water quality, expansion of analysis items, and expansion of ISO certification.

c. Indicators to Monitor Progress

- Rate of compliance with water quality standards at the outlet of the WTP (ensuring the treatment process)
- Rate of compliance with water quality standards in water supply area with turbidity and residual chlorine (ensuring water safety)
    - FY2019 Results: Turbidity 100%, residual chlorine 100% (30 sites/month)
- Number of items regularly analysed in PPWSA (ensuring system for water safety)

d. Actions

Table 9.3.3 Actions for development (Water Quality Management and Monitoring, and water safety plan)

	Actions	2021-2024	2025-2027	2028-2030
Capacity development of water quality analysis	Collect information on atomic absorption spectrophotometers and other instrumental analysis methods (e.g., ion chromatographs, gas chromatograph mass spectrometers (GC/MS)) to enable analysis of all items in the NDWQS, and develop action plan that includes the timing of introduction, personnel assignments and budget.		→	→
	To improve the accuracy and precision of analysis by adopting the analytical methods specified in the NDWQS, using internal precision control, eternal training including QCM.	→	→	
	To expand water quality analysis items for ISO17025 certification for applying in all labs of each WTP, recheck all analytical procedures and update SOPs by utilizing external training and advice from experts.	- - → (Continue	- - →	- - →
	Promote the recruitment and capacity building of biologists to identify algae (especially microcystis).	→	→	→
Expansion of water quality monitoring	Conduct periodical monitoring of residual chlorine concentrations at particularly critical points in the water supply area.	→	→	
	Discuss to introduce more effective water quality monitoring system such as on-line at tap in distribution area transmitted to central lab. for turbidity, Cl, conductivity, pH.		→	→
	Collect information on algae-produced toxins (microcystins, etc.), consider exchanging information with relevant authorities, and establish and implement a raw water monitoring plan.		→	→
	Implement the Laboratory Information Management System software (LIMS) and connect all WTP labs to this central software.		→	→
Strengthening of water quality management	Update the water safety plan and identify areas for strengthening in the overall water quality management	→		
	Work with the Production Office and Laboratory to identify the sections responsible for the series of data evaluation and analysis.	→		
	To develop and secure staff capable of verifying and analyzing data, strengthen the capacity of lab staff in critical analysis of analytical results and forecasting of water quality changes by utilizing external water quality experts, training participation, and other opportunities.		→	→
	For the respond to emergency situations, the contents of the Water Safety Plan will be developed as SOPs for each work site, on which training will be provided.	→		

Source: JICA Data Collection Survey Team

(3) Distribution Control & Energy Efficiency

1) Current Situation

a. Control of production volume

The amount of water produced at WTPs is monitored by the SCADA system, which can be viewed at the control room in the headquarters, but the production control is decentralized and is carried out independently and cooperatively at each water treatment plant. The operation of Nirodh WTP adjusts to absorb the fluctuations of the production volume of Chamkar Mon WTP, and the Churoy Chamber WTP and Phum Prek WTP are mutually adjusting the volume of production each other. Each WTP has an annual plan for monthly water production based on historical records and water levels at each intake, but the actual situation is that the demand is currently exceeding the design capacity, so no adjustment of water production can be made. Even if a sufficient amount of water can be produced following the completion of Bakheng WTP, it is not simple to optimize and coordinate the production volume at each WTP because each is uniquely affected by the water demand of each area and the condition of transmission pipe network to accommodate ever fluctuating needs. In addition, the Bakheng WTP (Phase I, Phase II, and Phase III), Ta Khmao WTP, Phum Prek WTP (Phase III), Koh Norea WTP, and Ta Mouk WTP (Phase I) will be constructed sequentially based on the facility development plan of this study, and distribution control should change in a complicated manner accordingly. For this reason, it is advisable to establish an office in charge of "allocation" for all WTPs to supervise their respective production volumes.

b. Distribution Control

Since the distribution areas of the existing four WTPs are not separated, water pressure and water distribution control are highly difficult. The water distribution network has been divided into 118 DMAs, and the necessary valves and other equipment have been installed. However, the network is currently not taking advantage of the DMAs because enforcement of DMAs results in water shortages the suburban areas. Once the Bakheng WTP is in service and the production volume becomes sufficient, hydraulic separation of DMAs by closing boundary valves is planned.

c. Monitoring of Water Transmitted and Distributed

To monitor the water flow at each DMA, SCADA system has been installed. At the inlet of each DMA, flow rate and water pressure are measured every minute and recorded in a logger. The accumulated data is transmitted to the main server at the head office once a day. This means that the minute-by-minute data up to the previous day is available for reference but minute-by-minute real-time monitoring is not possible. In addition, water pressure is continuously monitored in the elevated tanks but water pressure and flow rate are not monitored in the transmission pipes. It is also necessary to monitor water pressure at several points within the DMA, including high elevation areas and the end of the pipes.

d. Operation of Pumps

Electricity tariffs in Cambodia, by policy, have been decreasing gradually since 2015, but are still high compared to neighbouring countries. Electricity costs account for 19% of PPWSA's FY2020 OPEX and 23% of FY2019. Since a major source of power consumption is the intake and distribution pumps, the priority for energy efficiency and conservation measures is to optimize distribution control and improve the efficiency of pump operation.

2) Measures for Development Toward 2030

a. Objectives

Establish a centralized distribution control room to control the water volume of production and distribution in real-time and optimize the transmitted water volume so as to improve energy efficiency.

b. Direction

The efficiency of each WTP and efficient distribution area of each WTP are comprehensively evaluated, and the production of each WTP will be mutually controlled for each DMA. By monitoring the flow rate and water pressure of each DMA, the accumulation of the trend of demand fluctuation by area can help to optimize the efficient distribution control and the management of production volume to meet the demand. In assessing the efficiency of each WTP, optimal production volume will be studied by considering seasonal and hourly variations based on historical data.

c. Indicators to Monitor the Progress

- Electricity consumption per distributed water volume at each WTP

d. Actions for Development

Table 9.3.4 Actions for Development (Distribution Control & Energy Efficiency)

	Actions	2021-2024	2025-2027	2028-2030
	Use electromagnetic electrodes to add real-time measurement points (flow rate and water pressure) on transmission pipes (at critical points and ends in the DMA at present). Connect this data to the existing central control system	⇢	⇢	⇢
	Develop staff to work in distribution control	→	→	
	Launch distribution control unit upon completion of the Bakheng Phase I WTP	→		
	Conduct F/S on the introduction of optimization tools for pump operation and management		→	
	Introduce real-time optimization tools for pump operation and management (if energy savings are achievable)		→	→
	Monitor power consumption in each treatment process and detect anomalies, if possible	⇢	⇢	⇢

Source: JICA Data Collection Survey Team

(4) Maintenance and asset management

1) Current situation

This section covers the daily maintenance and management of all equipment, including electrical, mechanical, and electromechanical equipment, as well as sensors and various IT network equipment, etc. Maintenance and management at PPWSA are generally at satisfactory levels. There are no critical issues but items that can be improved upon from the perspective of preventive maintenance and asset management are discussed below.

a. Daily Maintenance Activities and SOP

SOPs have been established for the operation and maintenance of all facilities and equipment, and the CCM, which was handed over in December 2020, is currently in the process of developing SOPs. The aspect of ensuring the implementation of SOPs is confirmed during the personnel evaluation. As for systematic confirmation of the implementation of SOPs, the Inspection Office checks the monthly reports of maintenance records from the viewpoint of internal control, but there is no checking system based on the records of each item of equipment.

b. Data Handling and asset management

O&M works are recorded in accordance with SOPs by the person in charge of the Mechanical and Electrical Office assigned to each WTP as well as by operators in WTPs. The Production Office and the Machinal & Electrical Office, which receive the reports, do not have the time to sort the collected data and analyse the data which may lead to developments in future operations. Maintenance records are kept, but they are not managed as an asset ledger from the perspective of asset management, where logs by facility and equipment can be checked and referred to for renewal. For example, analysis and comparison of electricity consumption by WTP. Similarly, the Maintenance Network Office, which is in charge of the maintenance and management of the IT system, mainly the SCADA system, has not been able to evaluate the performance of each equipment from the maintenance records and reflect it in the maintenance management plan. In terms of asset management, it would be useful to compile technical documents, manuals, completed drawings, periodic inspection records, and repair histories in addition to the asset ledger.

c. Status of Equipment

Automatic water quality analysis equipment is installed in the WTPs, but accuracy is a cause for concern. The equipment requires frequent calibration, the sensors have a short life span, and replacement parts are relatively expensive and time-consuming to procure, making it difficult to achieve "zero defective equipment" operation.

d. Issues for Implementation of Maintenance

In recent years, WTPs have been operating at full capacity or above in order to secure the required volume of treated water and operating pumps in WTPs has become complicated. Standby pumps are used in service operation, spare parts must be secured, and maintenance schedules must be carefully planned. Major equipment and facilities have not been able to shut down for maintenance, which is a major challenge. Any unplanned of a WTP it will create significant negative impacts. This forces PPWSA to observe equipment more carefully than typically required.

For pumps, which have a significant impact on water supply in the event of a malfunction, the system of preventive maintenance needs to be strengthened. The condition of individual equipment should be monitored in detail through the development of equipment ledgers. Conducting periodic inspections such as deterioration of intake and distribution pumps and conducting efficiency surveys will help avoid sudden breakdowns and other problems. This can be used for development and maintenance methods, such as adding a rotation speed control (VSD).

2) Measures for Development Toward 2030

a. Objectives

To avoid fatal failure of equipment, improve procedures and tools, and set up a maintenance audit office to ensure that maintenance is carried out in accordance with SOPs.

b. Directions

In order to prevent large impacts on water supply due to problems with equipment, information on individual equipment should be accumulated through the maintenance of equipment ledgers, preventive maintenance should be carried out, and responses to minor problems should be implemented firmly. It is necessary to develop the structure to confirm that the maintenance and management is properly implemented especially of newly introduced equipment, as well as electronic equipment with a short lifespan and high replacement cost.

c. Indicators to Monitor Progress

Establish a Maintenance Audit Office to verify appropriate indicators.

<u>Examples of indicators:</u>

- ✓ Percentage of malfunctioning equipment (e.g., recovery time of failed equipment, frequency of data accuracy checks, number of major problems (affecting water supply))
- ✓ Expenditure on repair and maintenance
- ✓ Budget for preventive maintenance

d. Actions

Table 9.3.5 Actions for development (maintenance, asset management)

Actions	2021-2024	2025-2027	2028-2030
Create a Maintenance Audit Office within the Production & Distribution Department. The office is in charge of conducting quarterly audit of equipment condition and respect of maintenance schedule in each WTP and on the network.	→	→	→
Implement a strict policy with zero tolerance for defective equipment (corrective maintenance).	→ (Continue)	→	
Conduct drill for critical failures. (Identify critical failure and define responses)	→	→	
Revise maintenance schedule of all equipment according to manufacturer's recommendations (preventive maintenance). Good with unified format for input it in asset management software in future.	→		
Carry out criticality analysis of equipment. Revise maintenance schedules according to findings. It may be with cooperation with Planning & Project Department in terms of engineering analysis experience.	→	→	
Prepare maintenance logbooks to trace all maintenance actions.		→	→
Apply the concept of ISO 55001 certification related to asset management systems			→
Train and assign staff for the maintenance of automation and measurement equipment.	→ (Continue)	→	
Train electrical staff to study its technical feasibility of regular pumps efficiency measurement (at least every two years for each pump), and to consider installing VSD to control for another option.	→	→	
Study feasibility of computerized Maintenance Management Software (CMMS) in terms of cost/benefit to trace equipment maintenance.		→	
Conduct lifetime study of electronic parts and budget security especially for spare parts; sensors of water quality monitoring system in WTP, sensors/meters of DMA monitoring system.		→	→
Review relevant SOPs to ensure stock and procurement management of chemicals, pipe materials, materials and equipment spares, etc.		→	
Conduct detail survey of meters in each DMA for its accuracy, and set replacement plan for inaccurate meters/sensors.	→		
Define program of valves operation and pipes flushing. Assign staff for program implementation (preventive maintenance). Good to start with end point of transmission, smaller size pipes at west area (D500-D600).		→	
Need to update SOP to Implement more stringent procedures for WTP cleaning. ✓ Cleaning of filter basins can be improved. For example, dirty water should be discarded after manual filter walls cleaning. ✓ Treated water tanks are not sufficiently cleaned and disinfected.	→	→	

Source: JICA Data Collection Survey Team

(5) Data Collection for Renewal

1) Current Situation

The target is all buried materials and equipment, including the water distribution pipe network.

However, as it is the largest asset of the water supply facilities, it is necessary to prepare and secure a budget for its renewal at an early stage.

The pipes of PPWSA are still relatively new. However, as pipes and distribution equipment are the largest asset class of the waterworks facilities, it is necessary to prepare and secure a budget for renewal at an earlier stage. In order to evaluate the conditions of the equipment and materials when renewal is required, it is essential to accumulate maintenance information up to that point. Establish a policy for collecting pipe condition data, including 1) systematic non-destructive testing of DIP corrosion, 2) photo record and assessment of internal pipe conditions, and 3) sampling and aging analysis of HDPE pipe materials. These works are conducted taking the opportunities to access the pipe during maintenance.

Since around 2016, asset management system called KIS has been applied, which can consolidate maintenance data such as the location of leakage, information of meters and pipes, the relocation tracks of pipes and accessories. When repairing leakages, PPWSA records the pipe diameter, pipe condition of the inside and outside, and corrosion status in the repair report with photos.

2) Measures for Development Toward 2030

a. Objectives

Implement systematic data collection about pipes in order to have enough data when preventive pipes replacement becomes necessary.

b. Indicators to Monitor Progress

- No. of records which shows pipe/equipment conditions. (=leakage repairing report)
- No. of records of main pipe/equipment conditions (=maintenance reports)

c. Actions

Table 9.3.6 Actions for Development (Data Collection for Renewal)

Actions	2021-2024	2025-2027	2028-2030
Continue systematic assessment of pipes internal condition each time a pipe has to be cut	- - - (Continue) - - -	- - - - - -	- - →
Collect information for outsourcing the analysis of corrosion/deterioration of pipes to its manufacturers		———	——→

Source: JICA Data Collection Survey Team

(6) Other Measures

Ensure safety management at all work sites. The main items are listed below.

- ✓ SOPs especially related to on-site work should ensure that safety measures are described.
- ✓ Confirm compliance with SOPs at each work site, including the use of helmets and other personal protective equipment.
- ✓ Maintain personal protective equipment and instruments for measuring oxygen concentration and temperature at the work site in good condition.
- ✓ Establish a schedule for checking the safety of fences, locks, etc. for safety measures at each work site.
- ✓ Assign a safety manager to each work site.
- ✓ Establish an emergency contact system in the event of an accident and conduct regular drills.
- ✓ In cooperation with Admin& HR Department, conduct regular safety management training for relevant staff and supervising safety training for safety managers.

9.3.3 Commercial

(1) Customer Relation and PR

1) Current Situation

a. Transfer of Duties to the Branch Office

The branch offices have been strengthened in line with the M/P (2017) suggestion and expanded to reach out to customers.

- With the expansion of the water supply area, it is essential to transfer duties to the branch offices to: 1) improve service by being closer to customers, and 2) increase operational efficiency by reducing staff travel time.
- The branch offices have been added within the elevated water tank compounds and connected to the head office via the intranet so that revenue operations can be carried out in real time.
- Customer Relation Office remains at the head office to provide services to the central area, support branches, and make policy decisions and management.
- After the operation of Bakhaeng WTP starts, additional branch offices will be considered as needed as the water supply area expands. The current status of the transfer is shown in ***Table 9.3.7***.

Table 9.3.7 Status of Transferring Customer Service-Related Operations to Branches

Related duties	Head office	Chrang Chamres (Russy Keo)	Pochetong (Por Sen Chey)	Choam Chau (Por Sen Chey)	Ta Khmao	Niroth WTP (Chbar Ampov)
1. Meter reading& collection	✓	✓	✓	✓	✓	✓
2. House connection & disconnection	✓	6 teams stationed in Head Office. Each team covers responsible areas specified for easy transportation. Difficult to decentralized due to stock management and the limitation of skilled staff.				
3. Meter maintenance	✓	Teams are assigned by district. This work can be decentralized in the future.				
4. Customer service	✓ (Main)	✓	✓	✓	✓	✓

Source: JICA Data Collection Survey Team

b. Meter reading and billing

The introduction of the handheld terminal has reduced the workload of processing meter reading data, reduced data handling errors, and increased the payment period. For large customers, the more frequent meter reading has resulted in better reliability of meter reading.

- Hand-held devices have been distributed to all meter readers since 2016, and completed in equipping in May 2017. New SOPs were created for meter reading works including taking photos of the meter reads at the same time for data verification. By being able to distribute bills at the same time as meter reading, customers can receive bill earlier than before, and have more time to pay in time, by which the collection cycle has been shortened.
- The introduction of the Hand-held system improved the working efficiency; the number of meter readers has been reduced from 100 to 79. However, considering that the number of connections is still increasing at 25,000 connections annually and is expected to increase in the future, there is no plan for further reduction.
- Management of large “strategic customers”: Electromagnetic flowmeters have been installed in all of the 2 to 3 thousand target customers. For those customers, the billing cycle was switched to monthly.
- Automatic Meter Reading is currently being tested. After the trial stage to confirm connection to the software, the AMR would be expanded to all target customers.

c. PR and Customer Relations

Recently, due to the increase in demand and the expansion of the water supply area, customers have experience decreases in water pressure, fear of deterioration of water quality, and tariff revisions. As they do not feel that the service has improved, proactive PR activities and the development of customer service are needed.

- In Phnom Penh, in order to respond to the rapid increase in water demand, the water supply area has been expanded, the water production volume has been inadequate, and operation has become complicated due to the phased expansion of facilities, resulting in unstable water pressure.
- It is difficult to provide stable water services to customers due to unstable water pressure and water quality at the tap. In addition, water tariff was revised in January 2020. In order for customers to understand and have trust in PPWSA's activities, it is important to conduct more proactive public relations and customer relations activities to explain the necessity of the project and efforts to improve services.

[Major PR actions of PPWSA]

- Establishment of call centre and official SNS to ensure that customers have access to PPWSA.
- Holding regular resident meetings to explain water supply services in communities that will become new water service areas.
- Prior to the tariff revision, conducted a wide range of PR activities through TV, newspapers, and SNS.
- Publication of business and financial reports, mainly for investors (IR materials)

2) Measures for Development Toward 2030

a. Objectives

Enhance customer services and expand and strengthen public relations activities to improve customer understanding of PPWSA business and gain their trust.

b. Directions

- Strengthen the system for communicating information from PPWSA to promote customers' understanding of water services.
- Strengthen the system for collecting and managing customer opinions and complaints.

c. Indicators to Monitor Progress

The results of customer satisfaction survey (the reliability to PPWSA)

d. Actions

Table 9.3.8 Actions for Development (Customer Relation and PR)

Actions		2021-2024	2025-2027	2028-2030
Enhance customer service	Continue the decentralization plan step by step by transfer of teams and responsibilities as service area expanded:	- - - (Continue)	- - -	- - - →
	Design a customer relation platform to collect, respond, track and records opinions and complaints from customers by utilizing SNS	→		
	Implement the above customer relation platform and improve customer service based on the collected opinions.		———	——→
	Update customer contact information more frequently.	- - -	- - - (Continue)	- - - →
	Updating hand-held device software so as to input customer contact information at site for more efficiency.	→		
	Restart feasibility study to develop website enable to provide customers with a secure access to a customer space (consultation of invoices, requests, complaints etc.)		→	
	Develop website enable to provide customers with a secure access to a customer space (consultation of invoices, requests, complaints etc.)			→
	Study the methodologies of regular customer surveys on SNS	→		
	Carry out more regular customer surveys to understand the situation of water supply services and trends in water consumption and adjust tariffs accordingly		———	——→
	Apply Automatic Meter Reading (AMR) for large customers	→	(Continue)	
PR activities	Formulate PR strategy to utilize various kind of medias (SNS, website, TV, radio, and bill) by PR contents effectively.	→		
	Expand PR activities especially for water saving practice.		———	——→
	Development of PR materials; video clip for services, production, WQ	→	(Continue)	
	Expand educational program for children, regular observation tour of WTPs, water saving practice, preparing exhibition room.	→		
	Study management of water supply interruptions for works with the GIS and automatic posting on PPWSA's website. Possibility to send warnings (SMS, e-mails) to customers concerned.			→

Source: JICA Data Collection Survey Team

9.3.4 Accounting and Finance

(1) Water Tariff

1) Current situation

In the M/P (2017), the revision of water tariffs set in 2001 was identified as the highest priority issue. It pointed out that expenditures have nearly doubled since 2001 due to inflation, rising labor costs, and the inclusion of VAT; future facility expansion projects will require cash reserves; and the new water treatment plants to be built are too small to benefit from the economics of scale of operation and maintenance.

Based on the financial analysis, the M/P (2017) assessed that the average water tariff in 2015 was about 1,030 KHR/m^3, which is not financially sustainable, and recommended that the average water tariff should be increased to the level of 1,800 KHR/m^3 by 2022.

In line with the recommendations, PPWSA revised the tariffs in May 2017 and January 2020 as shown in ***Table 9.3.9*** below.

Table 9.3.9 Revisions of Water Tariff (2001-2020)

	2001~April 2017		**May 2017~ Dec. 2019**		**Jan. 2020 to present**	
Type of Customer	**Q'ty of water consumed (m^3/month)**	**Tariff (KMR/m^3)**	**Q'ty of water consumed (m^3/month)**	**Tariff (KMR/m^3)**	**Q'ty of water consumed (m^3/month)**	**Tariff (KMR/m^3)**
Domestic	0 m^3 ~ 7 m^3	550	0 m^3 ~ 3 m^3	400	0 m^3 ~ 7 m^3	400
			4 m^3 ~ 7 m^3	500		
	8 m^3 ~ 15 m^3	770	8 m^3 ~ 15 m^3	770	8 m^3 ~ 15 m^3	720
	16 m^3 ~ 50 m^3	1,010	16 m^3 ~ 50 m^3	1,010	16 m^3 ~ 25 m^3	960
					26 m^3 ~ 50 m^3	1,250
	Over 50 m^3	1,270	Over 50 m^3	1,270	51 m^3 ~ 100 m^3	1,900
					Over 100 m^3	2,200
Public Administration Institution and Embassy	Flat rate	1,030	Flat rate	1,030	Flat rate	2,500
Commercial, Autonomous State Authorities and Wholesalers	0 m^3 ~ 100 m^3	950	0 m^3 ~ 100 m^3	950	0 m^3 ~ 15 m^3	950
					16 m^3 ~ 45 m^3	1,100
					46 m^3 ~ 100 m^3	1,400
	101 m^3 ~ 200 m^3	1,150	101 m^3 ~ 200 m^3	1,150	101 m^3 ~ 200 m^3	1,700
	201 m^3 ~ 500 m^3	1,350	201 m^3 ~ 500 m^3	1,350	201 m^3 ~ 500 m^3	2,100
	Over 500 m^3	1,450	Over 500 m^3	1,450	Over 500 m^3	2,400

Source: JICA Data Collection Survey Team based on PPWSA data

In the revision, the target average water tariff was initially set at 1,700 KHR/m^3, but after review during the approval process, 1,350 KHR/m^3 was accepted, and to complement this, a reduction in the interest on the government loan to PPWSA from 6% to 0.65% was applied.

The tariff revision in 2017 lowered the domestic tariff for the small consumption segment, resulting in a slight decrease in the average water tariff to 1,002 KHR/m^3 in 2018[1]。The revision in 2020 subdivided the domestic and commercial tariff segments and increased tariffs for all categories except for small domestic use, which increased the average water tariff to 1,335 KHR/m^3 (2020).

Figure 9.3.4 and ***Figure 9.3.5*** show the ratio of billed amount of domestic connected customers by amount of water used, comparing 2015 and 2020. The red line indicates the segment boundary of tariff. The M/P (2017) proposed to revise the unit price for large users to encourage water conservation. Looking at the graph after the tariff revision in 2020, it can be said that by setting a new tariff segment at 25 m^3 and above to raise its unit price, the new rate has succeeded in reducing the burden on low-consuming customers and increasing the percentage of the bill for large consuming customers.

[1] JICA. 2020. "The Project for Water Supply Expansion Project in Ta Kmau"

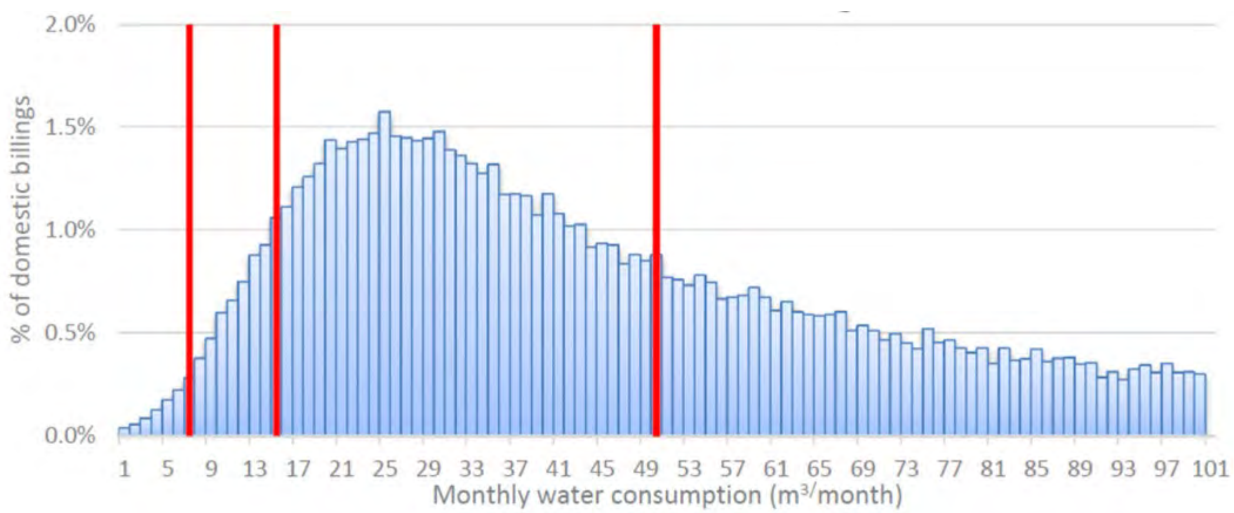


Figure 9.3.4 Ratio of Billed Amount of Domestic Connected Customers by Amount of Water Used (May-June 2015)

Source; the M/P (2017)

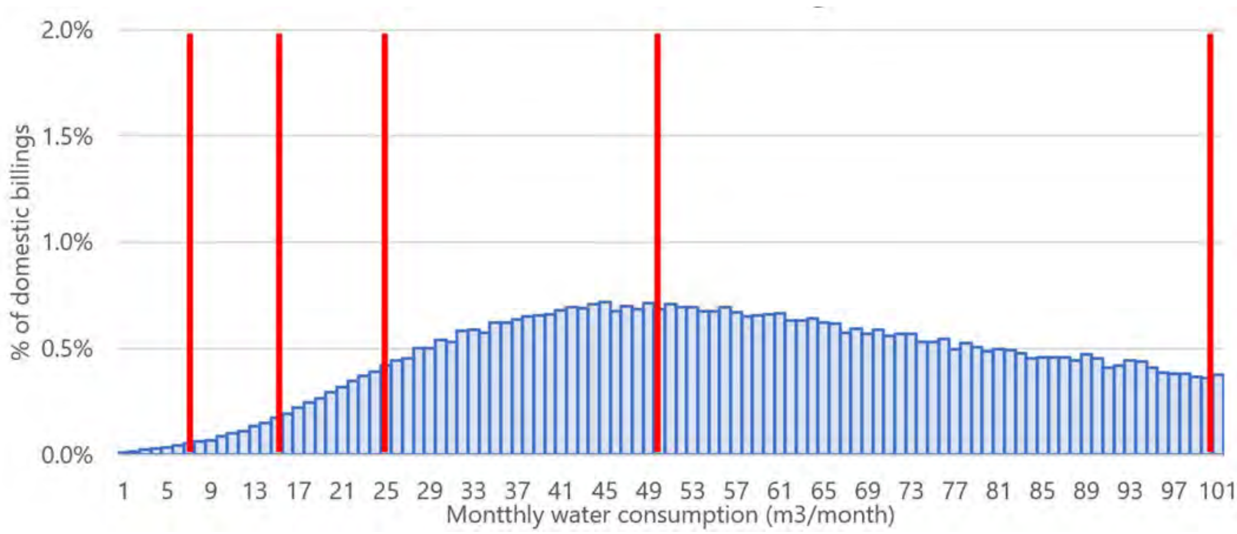


Figure 9.3.5 Ratio of Billed Amount of Domestic Connected Customers by Amount of Water Used (May - June 2020)

Source: JICA Data Collection Survey Team based on PPWSA billing data

One possible reason why the overall average tariff did not increase as much as expected is the impact of COVID-19. Since January 2020, when the tariff revision was applied, the amount of water consumed decreased significantly, coinciding with the spread of the pandemic. ***Figure 9.3.6*** shows the amount of water billed by customer category for 2019-2020. The billed water in 2020 was 35% lower in January/February and 25% lower in March/April compared to the same period of 2019. The percentage of water consumption by customer category has not changed significantly since 2019, with domestic consumption staying at around 50% of the total consumed volume, and commercial consumption at around 40%.

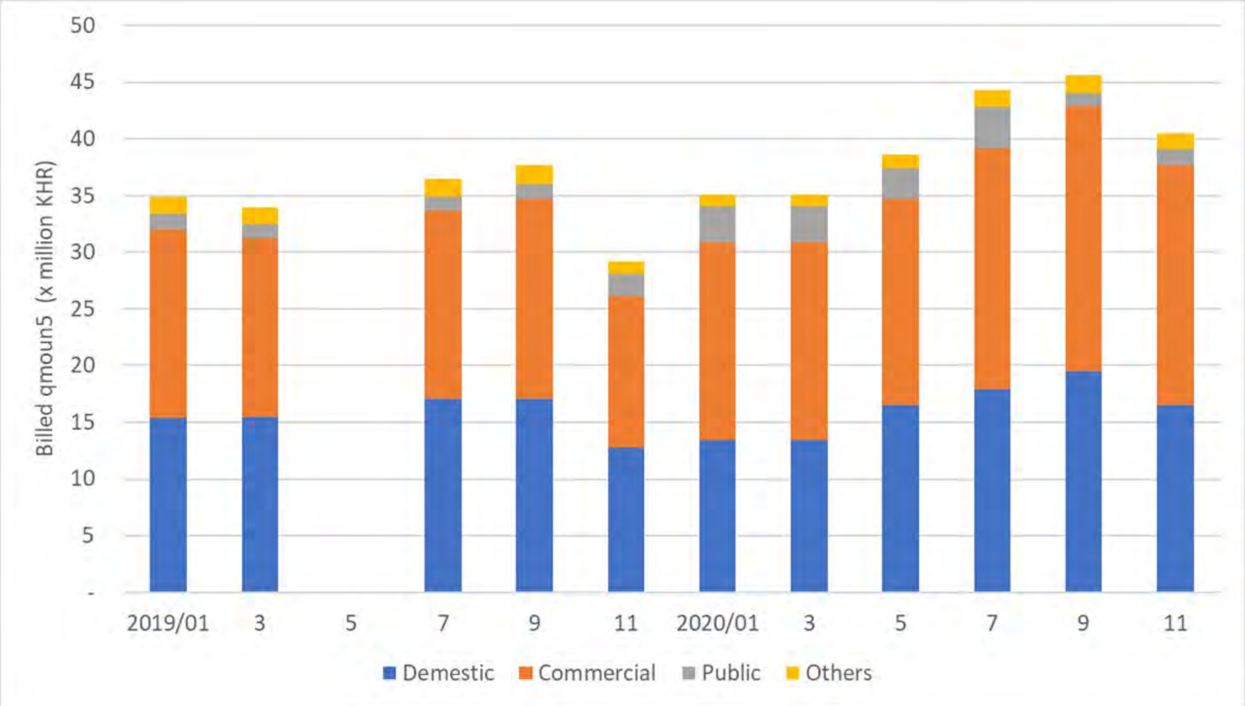


Figure 9.3.6 Billed Water Volume by Customer Category (2019 – 2020)

Note: Billing data for May 2019 is removed because some billing was stopped due to delays in the billing process and shows abnormal values.
Source: JICA Data Collection Survey Team based on PPWSA billing data

2) Measures for Development Toward 2030

a. Objectives

Revise water tariffs in order to ensure financial sustainability of PPWSA and to secure the necessary funds for project implementation as defined in the Master Plan, while taking into account the level of tariffs accessible to the low-income customers. Besides tariff revisions, various other measures should be studied in order to secure revenue.

b. Directions/Indicators to Monitor Progress /Actions to Implement

The levels for the revision of water tariff are studied in ***Chapter 12 Financial Analysis***. Other possible programs to secure revenue are presented below.

Refund of Input VAT

As required by the relevant Prakas, PPWSA is not currently collecting VAT on its water sales. PPWSA on the other hand pays VAT on operating costs including raw materials while VAT is essentially a tax to be paid by end customers, not a business enterprise. It may be possible for PPWSA to collect VAT on its water sales to cover the VAT payment on operating costs, however, it requires to modify the Prakas and may pose a concern about VAT on drinking water which is basic human needs. Therefore, it is rather recommended for PPWSA to negotiate with the government to have refunds on its VAT payment.

Minimum Charge on Water Connections

PPWSA's water connections is increasing approximately by 30,000 per year, and there increases customers which do not use water at all after connecting to the water network. It is recommended for PPWSA to introduce minimum charge on such water connections without actual consumption in order to cover installation costs as well as maintenance costs to avoid such cases. Pricing strategy on minimum charge shall be studied further.

Automatic Inflation Adjustment on Water Tariff

In Cambodia, consumer index has increased by 3% per year in last 10 years and PPWSA has been suffering from increases in labor and raw material prices. Modification of water tariff is subject to approval and authorization by the Cambodian government and therefore time-consuming. In order to minimize the gap between the cost increase by inflation and water tariff, it is recommended to introduce a mechanism that water tariff would be automatically adjusted to inflation according to the pre-determined methodology.

(2) Other measures

1) Acceleration of Updating Financial Plans

Whenever an event is identified that may have a significant impact on the financial plan, the annual plan should be updated immediately, without waiting for the annual update schedule. This enables top management to immediately assess whether the cash on hand will not be short or whether additional borrowing will not violate the covenants of existing loans in situations where emergency expenditures are required. For the reflection in and updating of the annual plan, it is necessary to establish work procedures within the department, and to decentralize the work with clarification of the responsibilities of each officer so that it can be carried out quickly.

9.3.5 Administration and HR

(1) Management of Staff Numbers

1) Current situation

The number of PPWSA staff in recent years has remained appropriate at around 3 staff per 1000 connections.

The number of staff in recent years is shown in ***Table 9.3.10.***

Table 9.3.10 Number of Staff (2011 - 2021)

Item	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Number of staff	607	606	705	851	920	1,030	1,033	1,047	1,092	1,138	1,153
Number of connections	219,498	235,128	264,613	270,812	289,024	310,835	333,288	367,032	388,883	408,500	443,021
Staff number /1000 connections	2.77	2.58	2.66	3.14	3.18	3.31	3.10	2.85	2.81	2.79	2.60

Source：JICA Data Collection Survey Team: data up to 2015 are from the M/P (2017); thereafter, from PPWSA.

As a reference, the data on the number of staff in water supply utilities in neighbouring countries is shown in ***Table 9.3.11.*** The high-performing utilities have kept the number of staff low by taking advantage of scale merits as the business scale increases. As described below, it is expected that the number of staff per 1,000 connections should be maintained at around 2.5, referring to these figures, as PPWSA's business expands about twice in the next decade.

Table 9.3.11 Staff Number Comparison with Neighbouring Utilities

Water supply utilities	Number of connections (x1000)	Staff number per 1000 connections	Data
MWA, Bangkok, Thailand	2,281.1	2.34	2016*
SYABAS, Kuala Lumpur, Malaysia	1,487.0	2.14	2007
Maynilad, Manila, Philippines	1,312.2	1.70	2016*
SAWACO, Ho Chi Minh City, Vietnam	1,268.7	3.86	2016*
PUB, Singapore	1,232.0	1.01	2008
Manila Water, Manila, Philippines	676.0	2.22	2009
Hanoi WSC, Ha Noi City, Vietnam	514.3	7.37	2015
PPWSA, Cambodia	443.0	2.60	2021
HPWSCO, Hai Phong City, Vietnam	271.0	4.16	2015
Da Nang WSC, Da Nang City, Vietnam	234.4	2.63	2016*
MCWD, Cebu, Philippines	181.6	4.69	2016*

Source: JICA Data Collection Survey Team; data marked with an asterisk (*) are from JICA (2017), "Report on the Implementation of 4th Executive Forum for Enhancing Sustainability of Urban Water Service in Asian Region"; all other data are from the IB-NET database.

Personnel costs have been increasing year on year, with personnel costs per staff of about 49 million KHR (of which about 80% is paid to staff as salaries and allowances, etc.) in 2020, accounting for the highest percentage of operating expenditure (28.3%, 2020). Financially, it is considered necessary to continue to keep the number of staff per 1000 connections below 2.9 in the future.

On the other hand, according to the facility expansion plan, the coverage area will be expanded, and the main facilities, including WTPs, will have more sites spread out in the suburbs. Since some of WTPs are smaller-scale facilities, it is difficult to benefit from the advantages of scale in allocating personnel for operation and maintenance. In order to keep the number of staff within an appropriate range, it is essential to improve the skills of staff and the efficiency of operations.

2) Measures for Development Toward 2030

a. Objectives

Manage staff increase properly due to business expansion and keep the number of staff per 1,000 connections at about 2.5.

b. Actions to implement

- Encourage consideration to introduce technologies to control the number of staff, in coordination with each department.
  - ✓ Use technology to improve productivity in labour-intensive operations: further labour saving in meter reading and billing through the introduction of telemetering, and the introduction of automatic monitoring equipment and real-time monitoring systems at WTPs and transmission and distribution networks.
  - ✓ Improving the efficiency of administrative work in all departments: data processing (data accumulation, reference, analysis, and evaluation) through the utilization of ITC, and information sharing systems among departments (utilization of LAN, SNS, etc., especially for improving access to data during the field work)

- Management of the number of staff through the promotion of outsourcing: Even now, for the work of house connection in Commercial Department and the construction work in the Water Supply and Sanitation Subsidy Branch, when the workload exceeds a certain staff's working capacity, outsourcing is being implemented in order to properly manage the number of permanent staff while a certain number of permanent staff are secured to ensure the transfer of skills. It should be noted that hiring and increasing the number of permanent staff in a short period in response to the rapid business expansion will affect the management of the number of staff in the future. It is necessary to examine the operations for which outsourcing can be utilized, including PPWSA's non-core works such as security services and cleaning services at headquarters, WTPs, and branches.

The number of staff per 1,000 connections in 2021 is 2.6 and this study predicts that the number of connections will almost double by 2030. The number of staff in the future is planned to increase in line with the business expansion without significantly increasing the staff per connections ratio. The planned number of staff by 2030 is shown in ***Table 9.3.12*** and ***Figure 9.3.7***.

Since PPWSA does not employ mid-career staff, the number of staff is controlled by employment of young incoming employees. It is necessary to systematically secure the number of new hires while supplementing for the number of employees who left. The turnover rate of PPWSA is low, and although the financial forecast sets the turnover rate at 1%, the actual rate is even lower. In the table below, the turnover rate is calculated as 1%.

Table 9.3.12 Projected Number of Staff (2021-2030)

Item	Unit	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Number of connections	connections	443,021	469,864	499,527	527,925	627,784	662,709	697,033	736,927	779,614	827,591
Staff number/1000 connections	person	2.60	2.59	2.58	2.57	2.54	2.54	2.53	2.52	2.51	2.51
Total staff number	person	1153	1,217	1,288	1,355	1,525	1,604	1,682	1,773	1,871	1,981

(Annual retirees)	person	5	5	4	6	13	10	14	14	21	28
(Annual new employment)	person	71	87	82	120	130	132	111	118	136	144

Source: JICA Data Collection Survey Team (actual data for 2021)

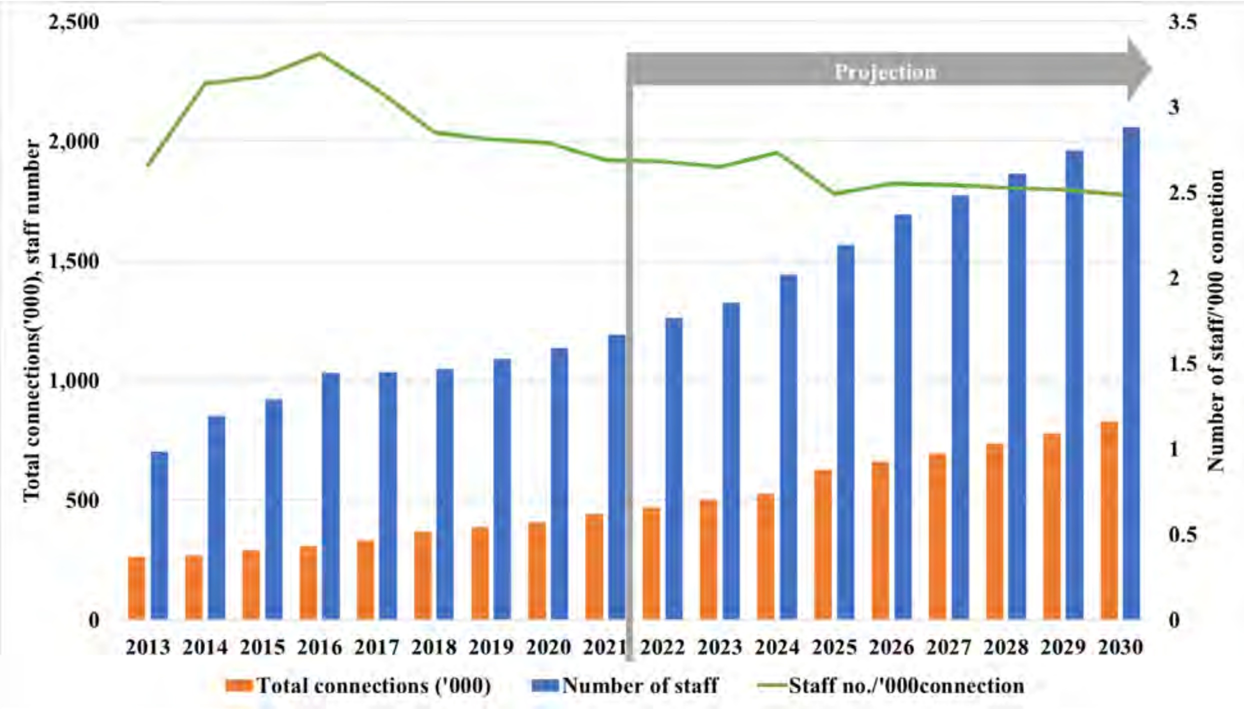


Figure 9.3.7 Staff Number and Total Connections (2013-2030)

Source: JICA Data Collection Survey Team; data up to 2015 referred to the M/P (2017), 2016-2021 provided by PPWSA

Based on the total number of staff, ***Table 9.3.13*** shows the projected number of staff in each department. Two departments, house connection team of Commercial Department and Water Supply and Sewerage Branch Office, have been limiting the number of staff by outsourcing when workloads become excessive. In projecting the number of staff, the two departments will continue to follow the same policy in the future, and are planning to control the increase in staffing due to business expansion.

As the scale of the business expands in the future, an increase in the number of staff is expected especially in labour-intensive duties such as meter reading, and operations and maintenance of WTPs s and transmission and distribution networks. For these operations, it is necessary to consider the introduction of technology from the perspective of reducing labour costs and enhancing services.

Table 9.3.13 Projected Number of Staff by Department (2021-2030)

Item	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
DG+ Secretariat	10	10	11	11	12	13	13	14	14	15
Audit	7	8	8	9	10	11	12	12	13	14
procurement	9	9	10	10	11	12	12	13	13	14
Inspection	12	12	13	14	15	15	16	17	17	18
Computer	25	26	27	29	31	33	34	35	37	38
Planning & Project	61	66	70	79	87	96	102	108	115	122
Production & Distribution	336	368	398	453	510	569	607	648	694	740
Commercial	357	371	384	409	434	460	477	495	516	536
Accounting & Finance	69	72	74	79	84	89	93	96	100	104
Admin & HR	118	123	127	135	143	152	158	164	170	177
Water and Sanitation Subsidiary Branch	187	195	202	215	229	243	251	261	272	282
Total	1,192	1,260	1,324	1,443	1,566	1,693	1,775	1,863	1,961	2,060

Source: Compiled by JICA Data Collection Survey Team based on PPWSA data. 2021 figures are actual numbers for July

(2) Human Resource Management

1) Current situation

By 2030, PPWSA's water supply business is expected to expand rapidly to more than three times in the production capacity, and about double in the number of connections, and it is necessary to secure and develop the human resources for implementing these projects and providing the expanded services. In addition to the human resource development plan shown in Chapter 9, this section presents the points that need to be strengthened from the perspective of human resource management.

a. Detect

In terms of finding human resources for recruitment, it is particularly difficult to recruit technical staff: the number of staff in electronics, electrical, mechanical, etc. is not sufficient to meet the need at all times. In the water quality laboratory, students from the Cambodian Institute of Technology (ITC) are received as interns, which is a good channel for recruitment. In the other fields, however, there is no practice of accepting interns. In 2021, a graduate school of water and sanitation engineering was opened at ITC, which will help in recruiting more specialized staff. As the scale of the business is rapidly expanding, it will be necessary to hire more engineers every year. To reach out to more qualified students, active collaboration with ITC, the only engineering university in Cambodia, is desirable.

b. Recruit

The number of staff to be recruited per year is assigned to each department, and each department conducts its own recruitment activities. PPWSA as a whole does not conduct any recruitment activities or PR and the entry to the selection process is based on the individual submission of CVs by job seekers or referrals by staff. Considering the significant increase in the number of staff to be hired annually in the coming years, it is more efficient for the Admin & HR Department to conduct recruitment activities once or twice a year where job information is open to the public and job seekers are registered, accepted, and screened in one operation. This will enable PPWSA to approach a wider range of qualified personnel and to secure human resources efficiently.

In assigning staff after hiring, it is effective to regard the first several years as a period to provide each staff with experience in several offices and to determine the suitable office to be assigned based on their aptitude.

c. Motivate & Retain

Quarterly personnel evaluations, annual salary base raises, and incentive systems have been established and salaries and other benefits are at competitive levels. In general, the motivation of employees to work is high. On the other hand, as the organization has grown and the working conditions have become attractive, more and more employees have joined PPWSA, attracted by the stable employment and high benefits, making it difficult for PPWSA to share a sense of membership in the organization, the organizational culture, and the mission of the waterworks business. In addition, as the work is mainly routine tasks defined in SOPs, young employees are less motivated to proactively tackle tasks and issues on their own.

d. Train & Develop

See Chapter 10 HRD Plan

e. Replace & Technical Succession

See Chapter 10 HRD Plan

2) Measures for Development Toward 2030

a. Objectives:

Strengthen human resource management strategies, especially recruitment, motivation, human resource development and knowledge transfer in order to realize rapid business expansion in the future.

b. Directions

Detect & Recruit: Approach a wide range of qualified personnel and consolidating the recruitment contact points into HR in order to enhance the efficiency of recruitment.

Motivate & Retain: Encourage motivation, especially among younger staff.

Train & develop: Structuring training and on-the-job training programs to improve the abilities of each staff member to improve operational efficiency, to acquire expertise to sustain new projects, and to secure core personnel for the organization.

Replace & technical succession: Develop executive candidates and encourage the transfer of skills and knowledge from highly specialized senior officers/staff to the next generation.

c. Indicators to monitor progress

- Turnover rate excluding retirees (within 1% per year)
- Revenue per staff, profit per staff (2020: approx. 285,000 KHR and 19,000 KHR respectively)

d. Actions to implement

Table 9.3.14 Actions for Development (Human Ressource Management)

Item	Actions	2021-2024	2025-2027	2028-2030
Detect	Set up a strategic partnership with technological institutions (ITC…) to detect high-potential students (for example, recruitment seminar at ITC, contacts through alumnus)	→	→	
	Strengthen cooperation with technological institutions by setting up special courses / programs related to water management, and dispatching PPWSA staff to teach classes (for example ITC is currently trying to set up a "water" program in partnership with foreign universities)		→	→
Recruit	Consolidate recruiting activities into the Admin & HR Department and conduct regular recruiting activities for public.		→	→
	Facilitate integration of on-boarding procedures for new employee by defining a standard path (e.g. orientation circuit including HR / IT / visit of all Depts, appointment of a mentor, quarterly new-comers seminar…)	→		
	Introduce a system that enables hired staff to be transferred from one department to another for the first few years in order to assess their suitability.	→	→	→
Motivate	Appoint younger employees as a leader of participatory activities		→	→
	Introduce Management by Objective (MBO) and consultations so that young employees can feel their growth and achievement.		→	→
	Identify areas requiring training for each staff in the procedures of personnel evaluations and reflect them in training plans.		→	→
	Transfer young staff to different jobs within the office to help them understand the entire related work.	→		
Train	See HRD Plan			
Replace	See HRD Plan			

Source: JICA Data Collection Survey Team

(3) Other Measures

- Quality management: Acquisition of ISO 9001 to standardize operations, enhance improvement capabilities, and compile and utilize business records.
- Safety management and working environment management: As the department in charge of safety management and working environment management for entire PPWSA, Admin Department should formulate management regulations and supervise the situation of compliance in each department, focusing on the items in the list below, and work toward improving the environment.

  - ✓ Confirm that safety management matters are included in the SOPs of each operation.
  - ✓ Ensure the use of safety equipment and protective gear such as helmets.
  - ✓ Assign a safety management supervisor for every on-site work.
  - ✓ Confirm that staffs are taking regular safety training.
  - ✓ Encourage regular health check-ups for all staff.
  - ✓ Manage working hours and the ratio of paid holidays taken by each department.
  - ✓ Confirm if there is any excessive overwork due to heavy or unbalanced workload.
  - ✓ Set up a consultation hotline for mental health and workplace environment issues.
  - ✓ Check the working room environment (noise, room temperature, brightness, size, etc.) from the perspective of the working environment.

9.3.6 Overall Institutional Setting

(1) Structure of Top Management Level

1) Current situation

The organizational structure of PPWSA consists of six departments and offices directly under the Director General that are responsible for institutional control and the management of the Board of Directors. The organizational chart is shown in ***Figure 9.3.8.*** Six Deputy Director Generals are assigned to each of the six departments, and each of these Deputy Director Generals supervises Director, who is in responsible charge of each department.

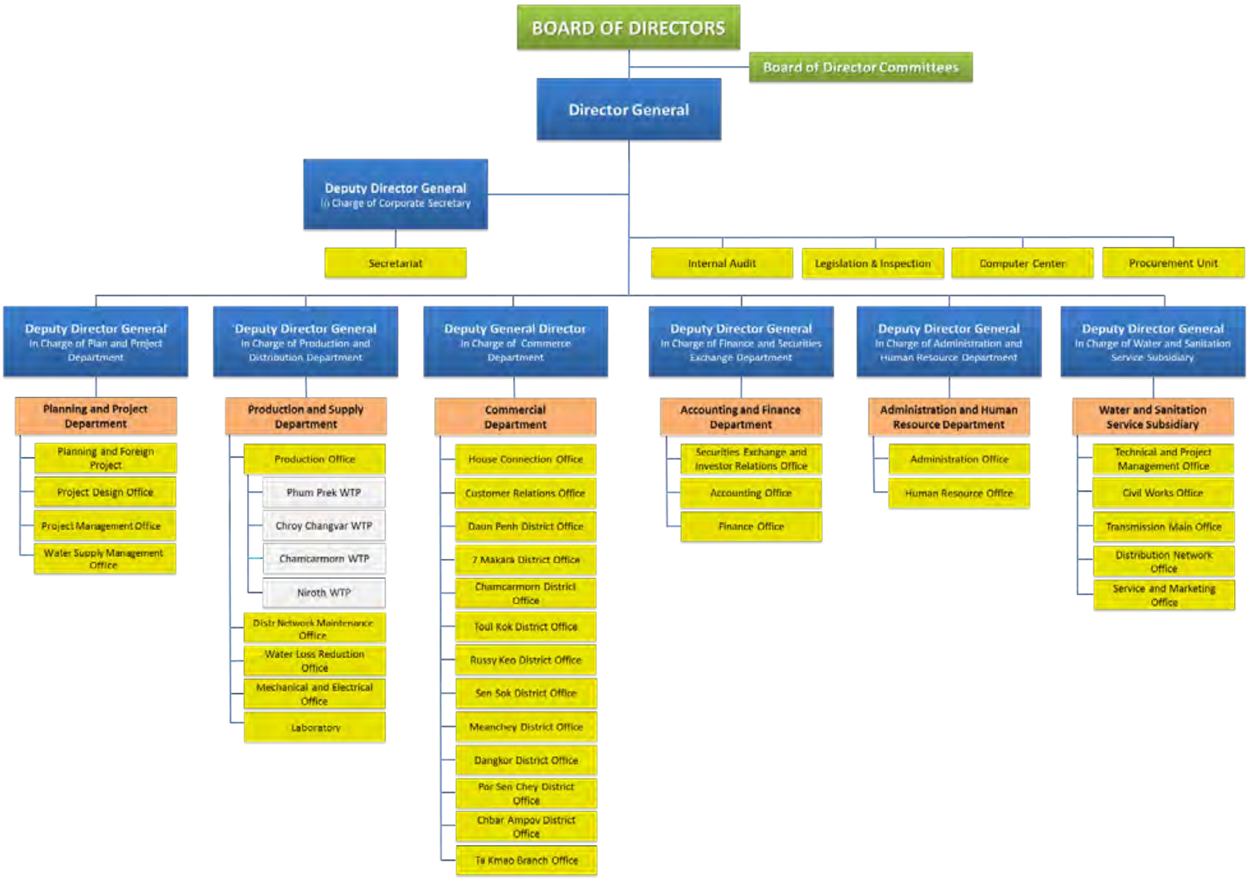


Figure 9.3.8 Organization Chart of PPWSA (repeated)

Source: JICA Data Collection Survey Team based on information from PPWSA

In the organizational chart, each Director is positioned at a subordinate level of the Director General. But in the actual operation of the organization, the Deputy Director General in charge supervises the Director, resulting in an overlap between the Deputy Director General and Director as the person responsible for each department. While the transfer of authority to the Deputy Director General is increasing, the responsibilities of the Director are likely to become ambiguous in this organizational structure. In principle, a higher-level position in an organization can take a broader perspective by supervising multiple lower-level positions. Thus, it is inefficient to have both the Vice President and the Director in charge of the same business area.

Clearly, decision-making authority should be transferred to lower levels as much as possible so that quick decisions can be made closer to the field and the organization as a whole can be more responsive to issues. Restructuring the responsibilities of the Deputy Director General and the Director may be effective method of accomplishing this. It is recommended that the decision-making authority at the department level, which is currently held by the Deputy Director General, be delegated to the Director.

On the other hand, the Director General is the only person in charge of cross-departmental supervision, and the structure is such that tge Director General is solely responsible for all cross-departmental coordination and discussions in the technical and management divisions. It would be preferred to have a structure that enables the Deputy Director General to oversee multiple departments in order to ease the responsibilities of the Director General.

2) Measures for Development Toward 2030

a. Objectives

By restructuring the responsibilities of the executive level, increase the speed of decision-making while improving the management control capability of the entire organization.

b. Directions

The Deputy Director General position is restructured into two people, one for technology and one for management, and the Directors are responsible for decision making within the departments. Based on the results of this survey, and referring to the organizational structure of water utilities with good performance in neighbouring countries, the proposed arrangement of Deputy Director General is as follows. The reorganization of the top management level will be phased as the current Deputy Director General retires, and the proposed organization in 2030 is shown in ***Figure 9.3.9***.

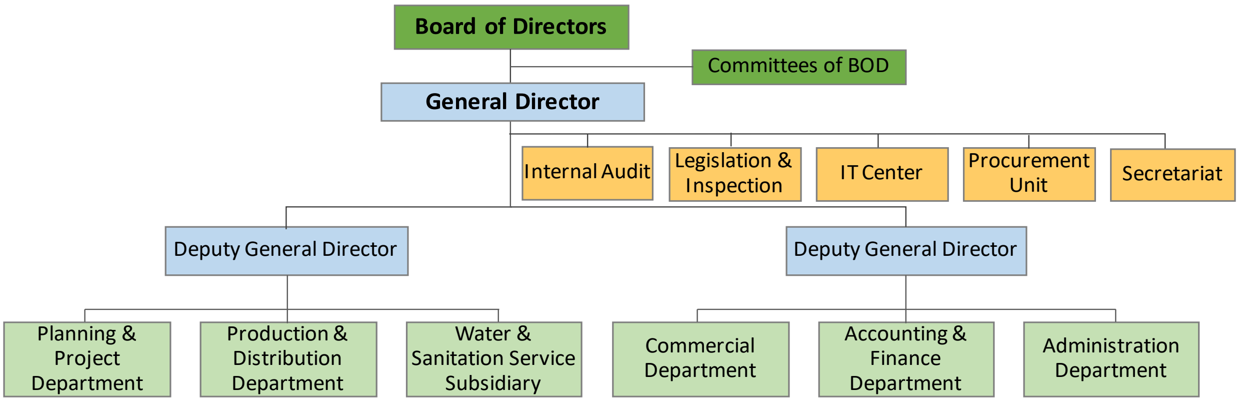


Figure 9.3.9 Management-Level Reorganization Plan

Source: JICA Data Collection Survey Team

c. Actions to Implement

Table 9.3.15 Actions for Development (Structure Of Top Management Level)

Actions	2021-2024	2025-2027	2028-2030
Clarify the current scope of responsibility of deputy director general and director, and assign responsibility for department-level decision-making to director.	→		
Define the respective responsibilities of each deputy director general of management, and one of technology	→		
Gradually integrate the supervisory authority of the management and technical departments when deputy director general is changed.	- - - (Continue)	- - -	- - - →

Source: JICA Data Collection Survey Team

(2) Risk Management And Response

1) Current Situation

The COVID-19 infection situation, which has been spreading since 2020, has had a significant impact on the continuous provision of services and business sustainability in the water supply sector. PPWSA has also experienced the implementation of staff shift work, delays in procurement of materials and equipment, and the impact on revenues due to a sudden drop in demand. In order to continue to provide water services in a stable and sustainable manner, it is necessary to study the vulnerability of the service and develop emergency response scenarios and procedures from the perspective of business continuity.

Currently, PPWSA reports on the risk factors and mitigation measures for each department in its annual report that is disclosed to investors. This report is limited to an assessment of individual events within the scope of each department's operations, and does not consider the risk assessment and impact on the entire organization caused by a single factor, the priority of response, etc., nor does it specify the department in charge.

As the first step in developing a business continuity plan (hereinafter referred to as "BCP"), it is necessary to identify the potential risks. Possible major risks in PPWSA operations include: 1) raw water contamination incidents; 2) various incidents in water intake and purification plants that cause production shortages (e.g., equipment failure, fire, etc.); 3) external factors (e.g., large-scale power outages, floods, social disturbances, telephone line failure, pandemics, etc.). By identifying the risks, the impact on business procedures can be assessed in what is known as Business Impact Analysis (hereinafter referred to as "BIA"). For critical operations of business continuity, the BIA estimates the impact that will be incurred from the time an emergency occurs until the time of recovery, and evaluates whether it is acceptable. For unacceptable risks, multiple measures should be considered in advance as mitigation measures, and a response plan should be formulated in consideration of cost and benefit. The BCP includes these preparatory measures as well as an emergency response plan in the event of an emergency.

The emergency response plan specifies the various actions to be taken from the time the emergency occurs until the business is recovered. Emergency response procedures enable an immediate response at respective work site by specifying the response to the anticipated situation in advance. In addition, the procedures should also include an emergency information sharing and decision-making system, consisting mainly of on-site information collection, reporting to decision makers and relevant departments, and making decisions and instructions. A clear system for sharing information in the event of an emergency enables a response based on systematic decision-making in the shortest possible time. In any emergency cases, the risk management system includes: responsible management (convening an emergency task force, as needed); preparation of a situation room with access to crisis communication means and related documents; coordination with the media if PR is needed for customers; coordination with relevant local agencies (hospital, fire department).

2) Measures for Development Toward 2030

a. Objectives

Assess PPWSA's general vulnerability to internal or external factors, conduct crisis analysis of equipment, define emergency measures, and train staff to respond to emergencies.

b. Indicators to Monitor Progress

- ✓ Formulation of crisis scenarios
- ✓ Conduct staff training in accordance with the emergency response plan

c. Actions to Implement

Table 9.3.16 Actions for Development (Risk Management And Response)

Actions	2021-2024	2025-2027	2028-2030
Determine the department and structure in charge of risk management for the entire PPWSA, as well as the members of the Emergency Response Team.	→		
Identify possible risks for each major facility and conduct a vulnerability survey.	→		
Establish crisis scenarios and formulate emergency response plans (simulations) for the event of a high-impact crisis.	———	→	
Conduct regular training and crisis simulation exercises.		———	→
Establish and progressively implement preparatory measures to mitigate crises that require too long a recovery time.		———	→
Introduce full-fledged facilities for crisis management (situation room: crisis management room)			→

Source: JICA Data Collection Survey Team

(3) Contribution for Other Waterworks, and Water Supply Sector

1) Current Situation

The vision of PPWSA clearly states that PPWSA assists other waterworks to supply potable water to their people.

2) Measures for Development Toward 2030

a. Objectives

- Utilize opportunities for support activities for other waterworks to consolidate knowledge within PPWSA, broaden perspectives on various issues and case studies in the waterworks business, and develop young staff and instructors as case study opportunities for solving business improvement issues.
- To date, PPWSA has performed its responsibility as a top runner by providing training to domestic and foreign utilities upon request, providing on-site assistance, and sharing PPWSA's knowledge at various seminars and workshops.
  In recent years, there have been some cases where PPWSA has been responsible for the operation of water supply in provinces.

  - ✓ In the Mlech district of Kamport province, where there were no private operators and water sources were scarce, PPWSA started a project at the request of MISTI to build (invest in) a WTP and then operate and supply bulk water to two private operators since the end of 2020. Currently, there is no revenue because the facility has achieved only partial operation of its capacity (2,000 m^3/day). But positive revenues are expected in the future. MISTI aims to model and promote this project for expanding water supply to rural areas.
  - ✓ Tboung Khmum Province, which was separated from Kompong Cham Province, had little operational capacity and human resources, and the water supply was limited to 4,000 m^3/day out of the 10,000 m^3/day capacity of the water treatment plant. MISTI approached PPWSA and the operation was transferred in August 2020. About 20 staff members are dispatched from PPWSA for operations. Water tariff have been maintained at the same level as before being transferred, and investments from PPWSA have been made to expand the distribution pipe network, etc. In 2021, water is being supplied to about 2,000 out of about 5,000 households.
- There is a MISTI-led initiative to establish a national waterworks training centre. The training centre will be open to all public and private waterworks operators in Cambodia, and the lecturers are expected to be senior officials of public waterworks including PPWSA, as well as invited overseas lecturers such as development partners. If realized, this will greatly contribute to the improvement of waterworks nationwide by spreading the knowledge of PPWSA.
- Contribution activities to other waterworks are mainly supported by section chiefs and above within PPWSA. In particular, the operation of the two provincial waterworks mentioned above is handled by experienced staff who are capable of providing on-site guidance and supervision on the areas such as O&M of WTPs, water quality management, and NRW countermeasures, which have high workloads even within PPWSA. Considering their roles in the primary work and the long-term sustainable arrangements, it is desirable to promote the development of the next generation by taking opportunities of such contribution activities.
- In addition to providing technical advice and accepting training, contribution activities for other utilities have the potential to grow into small-scale but income-generating businesses, such as creating models of operational know-how for small-scale water utilities in provinces, consulting on business management, and providing water quality analysis services at water quality laboratories. In addition to the accumulation of knowledge within PPWSA, this will provide an opportunity to assess the profitability of the business and consider the development of the business.

b. Indicators to Monitor Progress

- ✓ Number of staff involved in contributions to other waterworks.

c. Actions to Implement

Table 9.3.17 Actions for Development (Contribution for Other Waterworks, and Water Supply Sector)

No.	Actions	2021-2024	2025-2027	2028-2030
1	Support training and field instruction on a request basis for MISTI, as is currently in place.	- - - (Continue)	- - -	- - -→
2	Undertake construction and consulting for provincial waterworks/operators	- - - (Continue)	- - -	- - -→
3	Develop young staff through support activities for provincial waterworks (several weeks to several months of field experience)		———	———→
4	Compile and promote sharing of case studies and other knowledge by staff who have participated in operations of provincial waterworks		———	———→
5	Actively consider requests from MISTI and other water utilities ・ Acceptance of training at PPWSA ・ Dispatch lecturers to the National Training Centre ・ Accumulate know-how on the operation of small-scale waterworks and disseminate it as a model. ・ Utilize small-scale waterworks sites to provide training activities to other waterworks/operators.	- - -	- - -	- - -→

Source: JICA Data Collection Survey Team

CHAPTER 10 HUMAN RESOURCES DEVELOPMENT

10.1 VISIONS AND FUTURE IMAGES

PPWSA has defined its vision for the organization as below.

> PPWSA's Vision
> "PPWSA is committed to the sustainable development of its potable water supply services, as well as providing services as a consultant and facilitator in order to ensure people in the other cities and provinces of Cambodia have access to potable water. PPWSA is also committed to assisting other developing countries to supply potable water to their people."

The development of human resources is one of the major issues facing PPWSA in realizing their vision and to ensuring the implementation of the facility improvement plan, operation and maintenance after completion of the facilities construction, and the operation and provision of services for the expanding waterworks business.

To achieve these, the vision of PPWSA's human resource development and the ideal PPWSA staff members are proposed as below.

> Vision of human resource development
> Develop staff's capacity to realize PPWSA's vision sustainably.
>
> The ideal PPWSA staff member;
> - has a sense of responsibility.
> - complies with the rules and regulations of the job and has high moral standards.
> - is willing to actively take on difficult challenges.
> - is good at team-working.
> - has rich work-related knowledges and expertise.

10.2 CURRENT SITUATION OF HUMAN RESOURCE DEVELOPMENT

10.2.1 SWOT Analysis

The results of the SWOT analysis regarding human resource development in PPWSA are shown below.

Table 10.2-1 Results of SWOT Analysis on human resource development

[Strengths]	[Weaknesses]
✓ Low turnover rate (less job separation). ✓ Good control of total staff number. ✓ Effective contract system to retain young engineers. ✓ Strong commitment of Top management in HRD. ✓ Plenty of internal/external trainings are provided continuously based on annual training plan. ✓ SOPs are fully utilized as training materials. ✓ Sufficient trainings on operational level based on SOPs. ✓ All training courses conducts achievement exams at the of the course. ✓ Willing to utilize outside resources for specific training fields. ✓ Many experienced internal trainers. ✓ Good control of training expenditure by development of internal trainers. ✓ Good data management/accumulation of HRD. ✓ 5S activities are actively implemented, good for working efficiency and safety. (5S: sort, set in order, shine, standardize, and sustain) ✓ Active contribution to provide technical knowledge-sharing to provincial waterworks.	✓ Low motivation of young staff to learn. ✓ Systematic transfer system of technologies and experiences to next generation is not established. ✓ No long term HRD Plan. ✓ Officers' insufficient understanding of HRD. ✓ Training courses are not well structured to help staff accumulate and develop their skills and knowledge step by step. ✓ Difficult to implement specific training with engineers as needed. ✓ Hard to provide working experiences for executive candidates of wide range of duties. ✓ Each staff works for particular office for long term. ✓ Support for self-development is not structured. ✓ Enhancement system for OJT improvement is not structured. ✓ No regular recruitment program. ✓ Limited training budget (only 0.3% of OPEX).

[Opportunities]	[Threats]
✓ New water related course in ITC (for recruitment, and refresh training). ✓ Strong support from international institutions. ✓ Many opportunities to have scholarship program of master course abroad. (1-2 person(s)/year). ✓ Continued good reputation of PPWSA. ✓ PPWSA provides training/advisory services to other water utilities.	✓ In several years, senior officers who have rich expertise and technologies are retiring. ✓ Difficult to find training resources for advanced technologies in Cambodia. ✓ Implementation of many development projects, which requires new/advanced technologies, complicated considerations. ✓ Informal use of PPWSA for special missions in other cities places a burden on PPWSA resources.

*SOP: Standard Operation Procedure
Source: JICA Data Collection Survey Team

The present staff composition of PPWSA by age and educational background is shown in the ***Figure 10.2-1*** below.

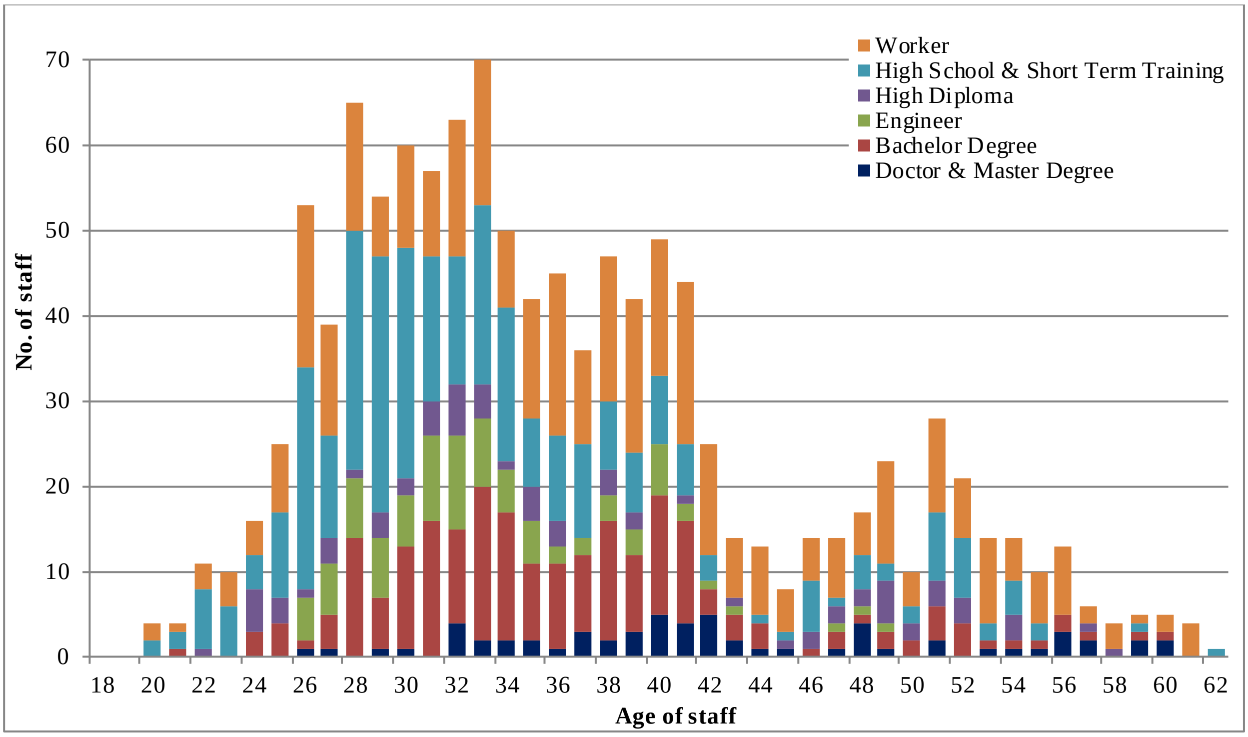


Figure 10.2-1 Composition of Staff by Age and Background (2021)
Source: PPWSA

Positions in PPWSA are mainly managed on the basis of educational background. The first generation of PPWSA employees are currently over 50 years old and mostly hold master's degrees or or other higher education degrees from abroad. This includes the current Deputy Director Generals and Directors. The second generation of PPWSA employees were hired during the period of reform and business expansion. They are mostly in their 30s and 40s and were brought in to implement the expansion projects. The third generation are mostly in their 20s to early 30s. They were hired after the Initial Public Offering (hereinafter referred to as "IPO") in 2012. In this cohort, there is la lower percentage of laborers and the percentage with high school and college degrees has increased significantly.

The first generation, top management of PPWSA, who contributed to PPWSA's reforms acquired higher education in Russia and other countries, accumulated experience through implementing successive projects with development donors over the decades, and played a central role in PPWSA for more than 20 years starting in their 30s.

As a result, the next generation of top managements has not been developed, and particularly because the number of staff in their 40s is now relatively small, people who can inherit the knowledge of the first generation is limited.

Furthermore, the ratio of young staff has been increasing in recent years, with 54% of the total staff being younger than 35 years old. The staff in their 40s, as the core of each section, are responsible for instructing and training the younger staff. As shown in ***Chapter 9***, PPWSA is required to continuously hire more than 100 new staff members every year as its business scale expands. Therefore, it is necessary to establish an effective training program from the time they are hired so that the new staff members can smoothly fulfil their duties as members of the organization.

Based on the analysis of the current situation, the main issues for the human resource development of PPWSA can be summarized as follows:

- ✓ To increase the working efficiency to properly control the increase in the number of staff due to the expansion of business scale, and to strengthen the capabilities of staff to handle and operate newly introduced technologies.
- ✓ Organizationally develop the next generation of top management to prepare for the retirement of technically capable and knowledgeable current management members.
- ✓ Limited opportunities to identify specialized training needs for technical staff and to provide training courses.
- ✓ Difficulty in recruiting and training highly specialized staff, particularly in technical fields.
- ✓ Efficiency and systematization of on-boarding training for young staff after their initial employment.
- ✓ Development of managers needed in line with facility expansion: managers of each site and team leaders of each technical field; which includes, at WTPs, O&M of WTP, maintenance of electrical and mechanical facilities, water quality analysis, and at branch offices, customer service, meter reading, water loss reduction.
- ✓ Improving the capacity of administrative departments as the scale of business expands: In addition to departments involved in operations as mentioned above, administrative departments will also face an increased workload. In addition to the increase in workload, the duties of administrative departments become more complicated; at Planning and Project Department in charge of a series of development projects; Accounting and Finance Department, which is responsible for financing and planning; IT Centre, which manages the communication infrastructure within the headquarters and with branches; and Administration and Human Resource Department (Admin & HR Dept.), which manage the expanding offices and the increasing staff.
- ✓ Opportunities to ensure that the organizational culture is passed on to younger staff, who are increasing in number.

10.2.2 Identification of Human Resource Development Needs

PPWSA conducts an annual training needs survey by questionnaire for each Department and formulates training plans based on the requests. On the other hand, there is no systematic mechanism for confirming the areas and fields that need to be strengthened from the perspective of the entire organization and examining medium- to long-term human resource development based on these areas.

In formulating the human resources development plan until 2030, in order to grasp the needs for human resources development from an organizational perspective, priority areas are identified from the following perspectives: 1) the current state of capacity in each field, 2) areas in which it is particularly difficult to recruit and develop specialized staff, and 3) areas that need to be addressed in future business expansion, which will be reflected in the development of training programs in particular.

(1) Maturity Assessment

As described in ***Section 9-2-1***, the Third Master Plan M/P (2017) evaluates the degree of maturity of “resources, tools and procedures mobilized to perform” initiatives for each business field and activity of PPWSA. In this study, the same classification of business fields and activities was applied to identify areas where significant improvement and development could be observed by 2021.

Here, although the maturity level of “resources, equipment, and procedures” is not directly linked to the need for human resource development, by confirming the current status of each area with low maturity scores, it is observed that they are caused by the lack of human resources and the issues of capacity development (see ***Section 9-3*** for the analysis of the current status of each area with low maturity scores and actions for improvement). Therefore, as shown in ***Section 9-2-1***, the areas with relatively low scores and no significant improvements observed, such as water quality analysis and management, maintenance of electronic equipment, customer service, human resource development, emergency response, and energy conservation, are considered to be in need of focused capacity development.

(2) Areas of Difficulty in Securing Human Resources

PPWSA's staff recruitment is mainly between the ages of 18 and 25, and there is no mid-career recruitment of personnel with work experience. Although PPWSA has been improving the salary levels of its staff year after year, it is as difficult as ever to recruit qualified personnel in specialized fields due to competition in the labor market. Furthermore, even after hiring, it takes time to acquire and develop expertise in some fields, requiring focused capacity building in the human resource development plan. In addition, after hiring, some fields require more time to acquire and develop expertise than others, and these areas should be included in the human resource development plan for focused capacity development. The following is a list of fields that are difficult to recruit or take time to develop.

Areas of difficulty in securing human resource: Civil engineering, hydraulic analysis, electricity, electronics, machinery, IT, water treatment, chemistry, biology, finance, accounting/auditing, quality management, safety management

The issues and improvements of the recruiting and hiring system are discussed in ***Section 10-3-5-2 Personnel Management***.

(3) Response to Business Expansion

Technologies that will be newly introduced as a result of the implementation of the projects proposed in this study, as well as areas that will require consideration in the operation of the expanded projects, are also prioritized for human resource development.

- ✓ Water treatment and hydraulic analysis: Long-term strengthening of basic knowledge to examine the appropriateness of new technologies.
- ✓ Distribution control: Extensive knowledge and application to manage water distribution while assessing energy efficiency, in the context of increasing number of water treatment plants and complexity of water transmission and distribution networks.
- ✓ Data evaluation and analysis: Areas related to monitoring and improvement of business operations and validation of introduced technologies.
- ✓ Asset management: Integration and utilization of information linked with maintenance records in preparation for facility renewal.
- ✓ Business management: In order to properly and efficiently manage an ongoing and expanding business, it is necessary to improve document management, data management, stock and inventory management, procurement management, quality management, safety management, and operation records and reporting throughout the organization.
- ✓ Risk management and business continuity and compliance

10.3 HUMAN RESOURCE DEVELOPMENT STRATEGY

In order to realize the vision of PPWSA and the ideal PPWSA staff member to become, the following strategies are defined based on the current situation.

- ✓ The number of staff is expected to increase as the business expands in the future, and in order to manage the staff number properly, it is increasingly important to improve the ability of each staff and to enhance the efficiency of their work.
- ✓ The target staff for strengthening will focus on the following three groups: 1) professional level: utilize foreign experts, training, master's courses, symposia, exhibitions, etc., to build expertise and absorb new technologies and knowledge; 2) mid-level: utilize domestic resources to develop candidates for chief and manager positions that will play a central role in the implementation of

operations; and 3) staff: promote OJT and SOP-based training to ensure the implementation of operations at the workplace.

- ✓ Training based on SOPs (Standard Operating Procedures) has been conducted for many staff members, and sufficient training opportunities for workers and operators have been provided. The SOP training should be continued and expanded in the future.
- ✓ Training should not be a single course, but a program that enables each staff member to deepen understanding the subjects and accumulate knowledge in line with their career. The training can be organized as a training program by position level and by duties.
- ✓ It is necessary to enhance the capacity of internal trainers and develop the next generation, as well as create and update training materials in order to respond to the increase in the number of training programs due to the increase in the number of young staff and the expansion of internal training areas.
- ✓ Current management and senior managers should drive the development of next-generation management in a systematic manner.
- ✓ As the number of younger staff gradually increases, a various training programs should be provided as well as support within the workplace should be strengthened in order to help them inherit the organizational culture and increase their willingness to learn.
- ✓ Young and next-generation leaders should be encouraged to expand their expertise and enhance their problem-solving abilities by utilizing opportunities of knowledge-sharing with and operation and management of provincial waterworks.
- ✓ A comprehensive human resource development system should be strengthened as a whole by effectively combining measures for human resource development other than training, and should be promoted as an organization.
- ✓ It is necessary to review “PPWSA Statute” so that PPWSA can implement these strategies.

Besides training, measures for human resource development include the promotion of On-the-Job Training (hereinafter referred to as “OJT”), strengthening of self-development, and knowledge sharing through internal study groups. Each of these measures has its own characteristics, as shown in the ***Figure 10.3-1*** below. For example, training based on Standard Operation Procedure(s) typically provides the job-specific contents of each job, which are more concrete and relevant to the job than regular training courses. Moreover, the content of the SOP training is expected to be immediately obtained and applied to work. As each of these measures for human resource development has different characteristics, they should be effectively combined to strengthen the entire system for comprehensive human resource development.

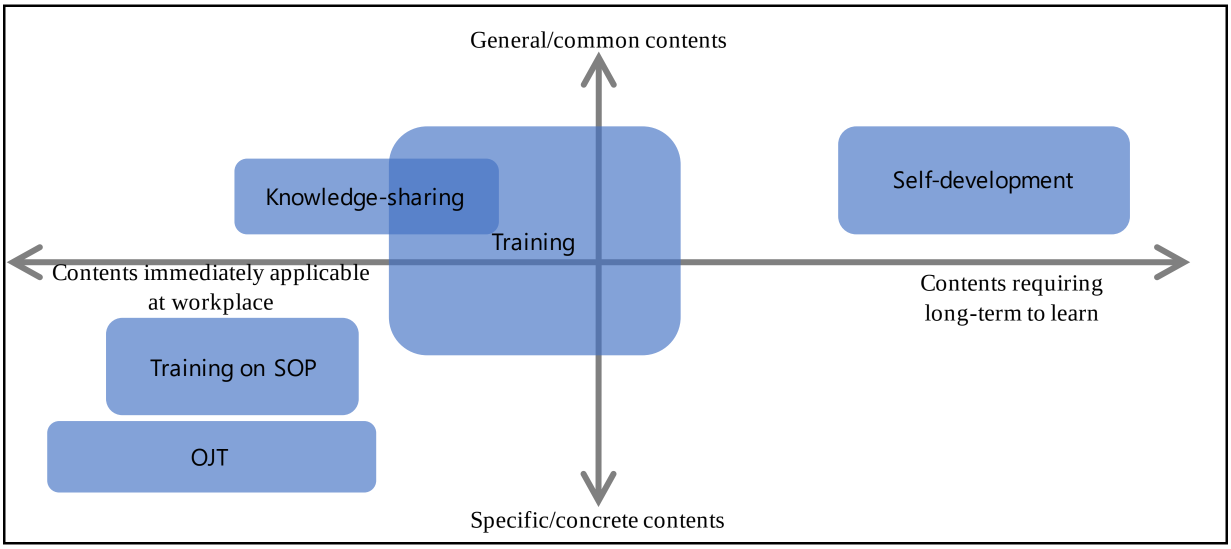


Figure 10.3-1 Area of Human Resource Development and Effective Methods
Source: JICA Data Collection Survey Team

10.4 HUMAN RESOURCE DEVELOPMENT PLAN

10.4.1 Training Program

(1) Training by Level (Group Training)

1) New Staff Training

This orientation is programmed as a group training for all new staff. Currently, Admin & HR Department conducts a simple orientation for new staff, followed by individual OJT in each department. By integrating this as a group training program, it is expected to reduce the burden and improve the quality of training in each department. Through this programmed training, new staff acquire basic knowledge about PPWSA and water supply service, which enhance the efficiency of OJT in their respective department afterwards as well as to build a peer network of staff and foster a sense of group membership of PPWSA.

Main Contents:

Overview of PPWSA organization, outline of water supply service, main duties and responsibilities of each department, staff service regulations, personnel evaluation, purpose and structure of SOPs, teamwork, customer service, site observation of major facilities (Nirodh WTP, etc.)

2) Young Staff Training

This group training provides all young staff in their third to fifth year of service. This aims to refresh their knowledge on the PPWSA business outline, business plan, and overview of the waterworks business. By inviting trainees from various offices, the training provides an opportunity for participants to think, exchange opinions, and learn by their own about the work and issues of each office, as well as to learn group discussion, facilitation, presentation, and report writing.

Main contents:

Overview of PPWSA's business and future plans and issues, each department's responsibilities and challenges, customer service, human resource development, tariff and business expansion, SDG, IT system and security, site observation

3) Basic Management Training

This course provides an opportunity for section chiefs and their candidates to learn the basics of management practices and enhance their managerial awareness, and to gain an accurate understanding of specific management procedures and techniques by focusing discussing and case studies of PPWSA.

Main contents:

PPWSA's vision and mission, mid-term plan, facility expansion and financial status, each department's responsibilities, challenges and future plans, departmental operations and budget planning and execution management, business operation monitoring, evaluation and reporting, staff management and development, compliance, health and safety management, overview of information sharing system etc.

(2) Skill Based Training

1) Basic Skills for Young Staff

These courses are designed for new and young staff to learn the basic business skills required for their work individually as a module. Active participation of young staff from each department will be encouraged. The courses aim to raise the fundamental ability of young staff to perform their duties, focusing on items related to their work. By conducting each course on a regular basis, it aims to improve the basic skills of all young staff. The training courses are listed in ***Table 10.4-1*** below.

Table 10.4-1 Fields and Training Courses of Basic Skills for Young Staff

FIELDS	TRAINING COURSES
(a) Basic business skills	Administration and Secretary work OPERACY (soft skill/management skill) Communication Skill; Negotiation skill, art of persuasion Meeting Minute, Reporting, documentation skills Presentation Skill

	leading the meeting
(b) Basic skills for site work	Safety and health management Site management Stock management Basics of construction work
(c) Basic computer skills	Microsoft Excel Microsoft Excel (Advanced) Microsoft Power Point Microsoft Power Point (Advanced) Microsoft Access GIS Data Input KIS Application (Software)
(d) English	English English (Speaking/communication skills) English (Official Doc. Correspondence)

2) Basic Skills on Management (Individual)

These courses are intended for section chiefs and their candidates to improve their knowledge and practical skills in management in areas that are particularly necessary for their work. Assuming to invite external lecturers, the participants of these trainings are expected to become lecturers for internal training in that field in the future. The training items are listed below.

- Management and leadership
- Human resource management
- PPWSA regulation, staff condition, compliance, health and safety management
- Facilitation skills for managers, trainers
- Negotiation and conflict resolution techniques
- Management and planning
- Results based program monitoring & evaluation
- Statistic for Analysis
- Project management
- Contract management
- Foundation of accounting and finance
- Asset management; data and inventory management
- Creativity, design thinking, and innovation for business
- Training of trainers

(3) Specific Training by Duty

These trainings are conducted in specific and expertise subjects directly related to the work of each department that require capacity development in an upcoming period. ***Table 10.4-2*** below shows the training subjects that need to be developed in the next 10 years, the target departments/offices for each subject, and the priority of implementation of the respective subjects.

Table 10.4-2 Subjects, Target Departments and Priorities of Specified Training

No.	Training subjects	Priorities of implementation	Target departments/offices										
			Planning & Project Dept.	Product. & Distri. Dept.	Commercial Dept.	Finance & Account. Dept.	Adm. & HR Dept.	Legislation and Inspection	Internal Audit	IT Centre	Procurement Unit	Secretariat	Water & Sanitation Brunch
I	**Internal training in PPWSA (12 subjects)**												
1	Annual training on SOP (continued)	◎		✓									
-	(PPWSA regulations, staff service regulations, compliance, health and safety management)	◎	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Management and Operation of Water Treatment Plant			✓									
3	Basics on Water process and water quality management for WTP operators			✓									

No.	Training subjects	Priorities of implementation	Target departments/offices										
			Planning & Project Dept.	Product. & Distri. Dept.	Commercial Dept.	Finance & Account. Dept.	Adm. & HR Dept.	Legislation and Inspection	Internal Audit	IT Centre	Procurement Unit	Secretariat	Water & Sanitation Brunch
4	Knowledge and management of O&M of WTP facilities	◎		✓									
5	Knowledge and management of O&M of network facilities			✓									
6	Maintenance of automation facilities/equipment, electronic, WTP			✓									
7	Maintenance of automation facilities/equipment, electronic, network		✓	✓									
8	General Knowledge on equipment/material being used in Waterworks										✓		
9	Reporting on "verification of Customer Payment" (Ratio)				✓								
10	Skill of usage and maintenance of water meter of size of 80mm and over				✓								
11	IT Risk Management	◎								✓			
12	Trainings of trainers	◎	✓	✓	✓	✓	✓						✓
II	**Training by outside lecturers/ institute in Cambodia (40 subjects)**												
13	3D Max	◎											✓
14	AutoCAD 2D & 3D	◎		✓									✓
15	Google Sketch Up			✓									✓
16	Microsoft Quick Book												✓
17	Microsoft Project	◎	✓										✓
18	QGIS			✓									✓
19	Legal Skill							✓					
20	Inspection Procedure	◎						✓					
21	Legislation							✓					
22	Foundation of Inspection Work							✓	✓				
23	Public Administration						✓	✓				✓	
24	Advanced Administration and Secretariat											✓	
25	Public Relation/ Communication with public				✓		✓						
26	Occupational Safety and Health	◎		✓	✓		✓						✓
27	Compliance	◎	✓			✓	✓	✓	✓		✓		✓
28	Training Management and Evaluation						✓						
29	Knowledge management/sharing						✓						
30	HR Development in an Institution (advance)	◎					✓						
31	Training Need Analysis (TNA)						✓						
32	Auditing Skill	◎							✓				
33	Risk Management							✓	✓				
34	Corporate Governance Auditing								✓				
35	Quality Management System Auditing								✓				
36	Project Appraisal					✓							
37	Advance Budget Planning & management					✓							
38	Long term planning and analysis (for finance)	◎				✓							
39	Taxation Regulation Update					✓							
40	Basics on International Financial Reporting Standards of Cambodia					✓							
41	Update on International Financial Reporting Standards of Cambodia					✓							
42	Financial report design on Navision	◎				✓							
43	Customer Management and Service				✓								
44	Public Relation Strategies				✓								
45	Database Administrator									✓			
46	Firewall Security	◎								✓			
47	Machine learning									✓			
48	Mobile App Development									✓			
49	Programming: database language (SAMs by MS)									✓			
50	Software project management									✓			
51	Comprehensive Cyber Security	◎								✓			
52	Visualization of software system									✓			
III	**Training in abroad, by foreign experts (28 subjects**												
53	Operation Manual of Water Supply Apparatus												✓
54	Infrastructure Development and Management		✓										

No.	Training subjects	Priorities of implementation	Target departments/offices										
			Planning & Project Dept.	Product. & Distri. Dept.	Commercial Dept.	Finance & Account. Dept.	Adm. & HR Dept.	Legislation and Inspection	Internal Audit	IT Centre	Procurement Unit	Secretariat	Water & Sanitation Brunch
55	Environmental and Social Safeguards		✓										
56	Financial Project / Analysis	◎	✓			✓							
57	Common Procedure for Project Management, Procurement, Finance		✓						✓				✓
58	Training for User of IT System for Public Finance Management		✓										
59	Hydraulic modelling, Data GIS Management, Water Gems		✓	✓									✓
60	Advance WaterGEMS	◎	✓										
61	Autodesk Revit (Structure, BIM Quantification and MEP Plumbing)	◎	✓										
62	ISO/IEC 17025: 2017 Quality Management System Risk Management and Auditing	◎		✓									
63	Laboratory Management and Internal Audit			✓									
64	Management of Testing Equipment and Chemical Waste for lab			✓									
65	New Technology and Innovation		✓	✓									
66	Water Quality Equipment Operation and Maintenance			✓									
67	Water Quality Management, Water Safety Plan			✓									
68	Water quality modelling in pipe		✓	✓									
69	New technologies and strategic management for NRW reduction	◎		✓									
70	Catchment management and Environmental conservation			✓									
71	Asset Management for maintenance			✓									
72	Efficient Water Distribution system/Pump Operation			✓									
73	Quality Management Course (Quality survey and Quality Control)			✓									✓
74	Pipe installation and Construction site management			✓									✓
75	Pipe Hydraulic Calculation			✓									✓
76	Warehouse Stock Management System	◎		✓	✓						✓		✓
IV	**Master's degree courses**												
77	Civil Engineering			✓									✓
78	Management of Technology (application and evaluation)												✓
79	Water resource			✓									✓
80	Water supply management												✓

Source: JICA Data Collection Survey Team

It is noted that there are many training subjects in ***Table 10.4-2*** for which appropriate training resources are difficult to find in Cambodia. In the past, although included in the annual training plan, trainings were frequently not held due to the lack of appropriate training programs in the country or due to the low number of participants who wanted to participate (According to the records since 2017, 15-20 external training courses were proposed in the annual plan, and every year, the half of the courses (10-15) were be implemented due to training resource constraints). For those training items, it is necessary to actively collect information on invitational programs for overseas training and to utilize external seminars.

In particular, it is recommended that areas where capacity developing is essential for the PPWSA and where these extra efforts are considered necessary be listed in the technical assistance programs for future planned facility development projects. The priority areas are as follows:

- ✓ Data analysis and evaluation: basic capacity for almost all departments, and specialized and advanced level analysis for Planning and Project Department, Production and Distribution Department, and Accounting and Finance Department
- ✓ Water quality analysis and management (including accuracy control)
- ✓ Specialized areas of maintenance and management of equipment for monitoring and control
- ✓ Planning and practical implementation of hydraulic analysis and distribution control

- ✓ Upgrade of business management: Refresh and evolution of overall business management, including document management, data management, inventory/stock management, and operation records and reports
- ✓ Risk management and Business Continuity Plan development from the perspective of business continuity
- ✓ Asset management: linkage with maintenance records that can be used for facility renewal planning

The expected technical assistance programs are listed in the table below.

Table 10.4-3 Prioritized training Subjects to Be Included in Technical Assistant Programs

Fields	Objectives	Target Trainees	Main Subjects
Data analysis and evaluation (Basic)	To raise the level of basic skills for using operational records and other data. Be able to extract points to be improved in business operations.	Almost all department. Staff in charge of compiling data	- Basic statistics for data analysis - Validity evaluation of data - Monitoring and evaluation of operational data and extraction of improvement proposals (exercise)
Data analysis and evaluation (Advanced)	Be able to evaluate projects based on data and extract recommendations for improving O&M.	Staff In charge of data analysis in Planning & Project Dept., Production & Distribution Dept, Accounting & Finance Dept.	- Basic statistics for data analysis - Validity assessment of data - Evaluation of performance-based projects - Extraction of improvement recommendations through analysis of O&M records (exercise). Cases: electricity consumption data that can be used to evaluate the efficiency of individual pumps, analysis and comparison of electricity consumption by WTP, analysis of production unit costs by WTP, consideration of proper arrangement of a responsible WTP to each demand area, and reflection of the results of the functional evaluation of each equipment into updating the maintenance plan.
Water quality analysis	To strengthen capacity of water quality analysis (including accuracy control)	Staff in laboratories	- Improvement of water quality analysis parameters, monitoring points, frequency, etc. (basic theory) - Review of water quality analysis procedures and updating of SOPs (OJT) - Risk management (ISO17025) (basic theory, OJT) - Management of analytical instruments (calibration, accuracy control) (basic theory, OJT) - Disposal management of laboratory waste (basic theory)
Water quality management	to strengthen the capacity for water quality management (strengthen the capacity for data verification of water quality monitoring results, analysis, reflection on water treatment, and study of countermeasures).	Office in charge of water quality management	- Advice on improvement of O&M of WTPs based on water quality analysis results (basic theory, exercises) - Examination of emergency response and formulation of SOPs - Examination of the adequacy of monitoring items on water treatment (SOP review) - Analysis of water quality changes in the distribution area (OJT)
Preventive maintenance and asset management	To strengthen preventive maintenance by using maintenance information.	Staff in charge of maintenance of electrical and mechanical facilities	- Fixed asset management based on maintenance records. (including a systematic maintenance management plan) - Preparation of documents for maintenance work: Maintain asset ledgers, compile technical documents, manuals, as-built drawings, periodic inspection records, repair history, etc. - Preventive maintenance of pumps; evaluation based on O&M records. Evaluation of pump efficiency and speed control (Variable Speed Drive: VSD)

Maintenance of facilities for monitoring and control	To secure specialized personnel to maintain and manage electronic equipment for monitoring and control.	Specific staff in charge of maintenance of electronical facilities	- Basics of equipment for monitoring and control - Maintenance of automatic measurement equipment (exercise) - Review of SOPs (OJT)
Hydraulic analysis and distribution control	(To be implemented in Bakheng project)	Staff in charge of relevant works in the Planning and Project Department	- Hydraulic analysis model based on water demand projection - Water pressure management using SCADA・Autodesk Revit
	To be able to operate water efficiently, which can be more complicated.	Staff in charge of relevant works in the Planning and Project Department	- Efficient distribution control and pump operation - Pipe network model using hydraulic analysis (for decision making) - Water quality degradation model in the pipe network
Business management	To upgrade the quality of business management and increase the efficiency of operations.	Managers of all offices	- Asset management, document management, inventory/stock management, procurement management, quality management, safety management, compliance - Operational records, reporting and presentation - Update of O&M manuals and SOPs (mainly for Production and Distribution Dept.)
Risk management and Business Continuity	To develop a business continuity plan for the major anticipated risks.	Office in charge (Internal Audit Office)	- Identification of risks, risk assessment - Identification of critical facilities and equipment - Emergency response planning and SOP development - Quality management, compliance, safety management

10.4.2 Promotion of OJT

PPWSA has SOPs in place for many regular works, and training courses on the contents of the SOPs are continuously conducted to ensure that the tasks are carried out in accordance with the SOPs.

In addition to this, it is essential for young staff members, who are increasing in number, to be guided by effective OJT at each workplace in order to grasp related tasks other than regular works and to understand related knowledge and basic theories behind SOPs. Currently, since OJT is being left to each department, even when managers are assigned to provide OJT instruction or try to improve the effectiveness of OJT, there are no materials they can refer to in order to learn effective OJT methods or specific examples.

Objective: To upgrade the quality of OJT in each workplace by establishing a system to develop OJT instructors within PPWSA as a whole so that they can guide young staff while motivating them to work.

- ✓ Actions:
- ✓ Recording of OJT: Human Resource Development Section (HRD Section) under Admin & HR Dept. initiate and develop a uniform format to record daily OJT in each office and accumulate experience. This can be used as a reference for finding good practices and challenges that are difficult to deal with.
- ✓ Development of an OJT case study handbook: HRD Section organizes the OJT case study handbook as a reference for improving OJT in each office. The handbook does not only explain the purpose, basic concepts, and methods of OJT, but also include many concrete examples of OJT in PPWSA.
- ✓ In preparing the handbook, a workshop on the contents of the handbook will be held by inviting some managers of offices in PPWSA where OJT is working well as resource persons, and opinions and examples of what OJT instructors should and should not do at each stage of OJT, such as assigning work and planning, daily monitoring and feedback, and review and evaluation, together with cases of successful and unsuccessful OJT will be collected and organized. The OJT records described in the previous paragraph will be used to provide a more practical case collection. Additionally, successful and unsuccessful cases should be collected and included as reference cases from literature and external training and seminars.

- ✓ Enhancing the awareness and skills of OJT instructors: Using the OJT case study handbook, workshops to develop OJT instructors are held targeting section chiefs and team leaders, with the resource persons mentioned above as instructors of the workshop. The participants exchange opinions and learn about cases in the handbook. Participants will receive an OJT instructor certificate.

10.4.3 Enhancement of Knowledge-Sharing

Objective: To share knowledge and experience within the workplace and build a culture of mutual learning as a learning organization.

Actions:
Each office considers how to materialize knowledge-sharing such as internal study sessions that are appropriate for the nature of the work and the size of the office, determine the implementation schedule, etc., and include them in the annual business plan of the office. The main implementation methods are shown below.

- ✓ Summarize the results and learning from seminar/training participants and share them in the workplace.
- ✓ Report and share examples of good practices and problem solving in the workplace and in relevant offices.
- ✓ Extract and share findings and creativity, improvements within the office through updating and reviewing SOPs.
- ✓ Utilize various guidelines and design guidelines to deepen understanding of related specified fields.
- ✓ Study the possibility of introducing new knowledge and technologies to the work and improving the work process through team-learning.

10.4.4 Encouragement of Self-Development

The effectiveness of human resource development depends largely on the willingness of staff to grow and learn. Therefore, supporting the learning and growth of staff who are willing to learn is particularly effective in strengthening their abilities. As an organization, supporting the self-development of staff can be expected to increase their engagement with the organization and stimulate the willingness of other staff to learn.

In order to promote the self-development of staff, the support system will be developed so that a wide range of staff can access it. In addition to the current system in which each office manager instructs staff to participate in training, there should be a system of incentives that encourages staff to focus on their own motivation and willingness.

Actions:

- ✓ Support system for participation in external training, seminars and events:
  - o It is necessary to set up a system in which, if staff are interested in external seminars and trainings other than OJT, they can make a request to attend them at any time, and after carefully examining the contents by their supervisor, be supported with training expenses or be allowed to participate during work hours. Based on the post-participation reports, if the content is useful, it can be expanded to call for wider selection of participants in the following years. Online seminars by IWA, FIDIC, etc. are also explored.
  - o Provide support such as tuition assistance to a certain number of young staff members every year, specifically those who wish to obtain a master's degree abroad in the future, in fields where continuous study such as English is effective.
  - o Expand support for young staff who are willing to go to high school, college or graduate school in Cambodia.

- ✓ Develop an incentive system:

- o Establish a system in which the participation records of external trainings and seminars are registered in personnel information and taken into account in personnel evaluations and promotions.
- o Utilize the participation in trainings and seminars and the acquisition of master's degrees and licenses as factors in personnel evaluations, such as promotion to management positions and as a requirement for the “expert staff” described below (see ***Section 10.4.5(4)***). Also, consider these achievements as a requirement for financial support for obtaining external licenses.

✓ Strengthen resources for self-development:
- o Strengthen the resource center (library) to enhance online access to reference and technical materials, accumulate past training materials in PPWSA, and explore e-Learning.
- o Look into strategic partnerships with external resource agencies (IWA, FIDIC, etc.)

10.4.5 Intensive Actions for Future Management/Officers

(1) Formulation and Implementation of a Succession Plan

As mentioned above, PPWSA’s top management have a high level of technical skills and knowledge through overseas study and successive project experiences with development partners. But, as many of the Deputy Director Generals and Directors are retiring within the next five years, there is an urgent need to develop the next generation of management. In the past, management was promoted and appointed from within PPWSA. Therefore, it is necessary to strategically accelerate the development of management from a long-term perspective.

<u>Actions:</u>

- ✓ Each Deputy Director General, Director, and Office Manager should clearly acknowledge that they are the person who are responsible for the development of their own successors, and each should formulate a succession plan.
- ✓ In the succession plan, each executive and senior manager should clarify what they emphasize in selecting their own successor (e.g., high vision, knowledge and experience in their field, contribution to the organization, management skills).
- ✓ Select candidates and identify areas that need to be strengthened for each candidate.
- ✓ Promote the delegation of authority and update information regularly on candidates to enhance their capabilities as needed. (See items below (2))
- ✓ Strengthen the capacity of the candidate through the formulation and implementation of a business plan for the department by the candidate.

(2) Delegation of Authority to Lower-Level Positions

In order to develop future management candidates, it is effective to provide them with experience in organizational decision making and problem solving. For this reason, it is necessary to clarify the scope of responsibility and delegate decision-making, which is currently concentrated mainly at the level of Deputy Director General, to the director level and manager level accordingly. This is a point that needs to be addressed not only from the perspective of human resource development, but also from the perspective of institutional management. Delegating organizational decisions to managers who are closer to the frontline can increase the speed and flexibility of decision-making, which makes it easier to take optional decisions on the issues. In addition, from the perspective of business continuity, it is desirable to clarify the duties and responsibilities and appoint an officer who can execute the duties on behalf.

<u>Actions:</u>

- ✓ Assign broader and more demanding tasks to the candidates and encourage them to solve problems through OJT (including work experience in provincial waterworks).
- ✓ Delegate authority over operations. Clarify the target tasks and scope of responsibility, and proceed with the transfer of not only business planning and execution management, but also budget and personnel decision-making authority.

(3) Clarification of Expertise and Securing Staff for Each Specialized Field

Since experienced staff will be leaving PPWSA in the coming years, it is essential to accumulate knowledge and to ensure the succession to the next generation and development of technologies in each specialized field within PPWSA in order to cope with the study of new technologies to be introduced and business expansion and to increase the efficiency of operations. In addition, with the expansion of the facilities, it will be necessary to secure a person in charge of each operational site and a leader in each field (e.g., O&M, maintenance of electrical and mechanical facilities, water quality management, etc., at every WTP, and customer service, meter reading, water loss reduction, etc., at branch offices). In order to ensure the same standard of work at each site, it is necessary to develop leaders with expertise so that they can be deployed in a timely manner up on the expansion of facilities and services.

Actions:

- ✓ Identify staff by area of expertise, by age, and strategically develop core personnel. The fields that require special expertise to be inherited are as follows:
    - o Technical fields: electronics, electricity, mechanics, civil engineering, chemistry, biology, IT (data analysis)
    - o Administrative fields: finance, accounting/auditing
- ✓ Identify the skill sets that should be acquired as a professional in each specialized field (can be used as base data for training needs assessment and as future development goals in personnel evaluation).
- ✓ Organize the knowledge of experienced staff from their experience in updating SOPs and responding to accidents, and share it in internal study sessions as knowledge-sharing activities.
- ✓ Prepare an archive of videos that are a few minutes long on each task, organized by theme.
- ✓ Ask retired personnel to be technical advisors as contract staff.
- ✓ Develop future core human resources in each specialized field, consider obtaining master's degrees for staff in different age groups.

(4) Introduction of Expert Staff System

In the current personnel system, the promotion path is for managers of each department, headed by Deputy Director General in charge, and the level of expertise is not factored into the career track. In addition to the general career path for managers who are responsible for business operations, it is advisable to develop another career path for specialists in order to give recognition to staff who develop their expertise and contribute to the organization. The field of deployment of "expert" is assumed to be mainly in the areas that require a high level of expertise as described in the previous section. In defining the fields, it may be helpful to specify more detailed areas of specialization. For example, the civil engineering field could be divided into hydraulic analysis and leak detection.

Staff appointed as "Expert Staff" are appointed to work as technical resources in the field in addition to their assigned duties in their offices. The expected roles of the expert staff members include the formulation and review of SOPs in the field, review of overall operations, preparation of training materials, training instructors, career support for young staff members, mid-term monitoring of operations, evaluation and analysis of accumulated data, etc. They are also expected to study new technologies, learn and report on advanced practices in other utilities, other sectors, international workshops, and other opportunities, and make recommendations on those application to PPWSA.

Actions:

- ✓ Clarify the specialized areas in which "expert staff" position is created.
- ✓ Appoint highly specialized staff to "expert staff".

10.5 IMPLEMENTATION STRUCTURE

(1) Stakeholders and Their Responsibilities

Human resource development is essential for sustainable business operation, and considering it as a long-term investment, an organization-wide system should be established to address it, including progress reports to the Board of Directors. For each of the human resource development measures described in the previous sections, the responsible department/office to implement and monitoring system are shown in ***Table 10.5-1*** below.

Each department ensures the implementation of each measure by describing specific details of implementation and management of each measure in their annual business plan. In particular, the Human Resource Development Section (HRD Section) under the Admin & HR Dept. acts as the lead office in reminding and encouraging the necessary activities for items to be implemented by each department, and periodically monitor and promote the implementation progress.

Table 10.5-1 Implementation and Monitoring Structure of Each HR Measure

Measures	Implementation and Management	Monitoring	Final Confirmation
1)Training program	Planned and implemented by HRD Section (each department cooperates in gathering information on external training programs)	Deputy Director General and Director in charge of HR confirms the implementation progress of annual training plan quarterly.	Admin & HR Dept compiles the progress of each measure of 1) ～ 5), and report to Board of Directors and annual report as an progress of Human Resource Development Plan.
2)Promotion of OJT	HRD Section set the details, describes them in annual business plan, and implements. Each office improves OJT.	Deputy Director General in charge of each office confirms the implementation progress of annual business plan quarterly.	
3)Utilization of knowledge-sharing	Each department sets the details, describes them in annual business plan, and implements.	Deputy Director General in charge of each office confirms the implementation progress of annual business plan quarterly. Admin. & HR Dept. monitor the progress of each department's plan and encourage regularly.	
4)Encouragement of self-development	HRD Section set the details, describes them in annual business plan, and implements with cooperation of each department.	Deputy Director General and Director in charge of HR confirms the implementation progress of annual business plan quarterly.	
5)Actions for future management	Each officer of each department sets their own succession plan, and implements. (Launch of "expert staff" is implemented by Admin & HR Dept by setting in their annual business plan)	Deputy Director General, Director in charge of each office confirms the implementation progress of annual business plan annually. Admin. & HR Dept. monitor the progress of each department's plan and encourage regularly.	

Source: JICA Data Collection Survey Team

10.5.2 Strengthening of the Implementation Structure

(1) Strengthening of HRD Section

In order to ensure the effective implementation of measures related to human resource development, the role of Administration and Human Resources Departments is very important, as shown in ***Table 10.5-1***, and HRD Section needs to be strengthened particularly. Currently, there are three staff in HRD Section, which is mainly responsible for the planning and management of training and related tasks. From now on, in implementing the human resource development plan in this chapter, HRD Section is expected to play a comprehensive role in the PDCA cycle of human resource development. Besides expanding the duties related to training management, HRD Section is responsible for implementing every human resources development measure, encouraging each department to promote its implementation, and monitoring the effectiveness of human resources development. The main responsibilities of current HRD Section and the expected duties in the future are shown in ***Table 10.5-2***.

In order to ensure the implementation of these tasks, HRD Section needs to be strengthened. By appointing additional management staff with management experience, the staff of the section will be strengthened, and the current three staff members will be gradually increased. In order to steadily carry out these operations, the current three staff members of HRD Section should be increased to five. In addition, by upgrading HRD Section from a section level to an office level, they will be able to communicate with each department and promote human resource development measures autonomously for the entire organization.

Table 10.5-2 Duties and Responsibilities of HRD Section

Main duties of HRD Section	Expected strengthened responsibilities
- Formulate annual plan for internal and external training for all departments - Manage the annual budget for training activities - Manage training records (internal and external) and compile implementation reports - Evaluate and review training materials in cooperation with the Training Material Evaluation Committee - Evaluate trainers and manage trainer allowance in cooperation with the committee - Coordinate accepting internship programs - Coordinate with participants in long-term training programs in country and abroad - Operate library and manage training materials	1. Expansion of works related to training management - Report the progress of the implementation status of annual training plan to the Deputy Director General in charge every quarter - Grasp training effects and identify new training needs by collecting the outcomes of personnel evaluation in all departments - Collect information on the implementation availabilities of prioritized external training programs 2) Implementation and promotion of other HRD measures - Implement activities to promote OJT - Identify and promote the knowledge-sharing activities specified by each department - Study and design in establishing systems to promote self-development - Monitor regularly and promote the succession plan for executive development formulated by each executive - Examine and promote "Expert staff" system 3) Monitoring and evaluation of human resources development - Compile and analyse data related to indicators for measuring the effectiveness of human resources development through the above operations

Source: JICA Data Collection Survey Team

(2) Formulation of Action Plan

In order to promptly implement the various measures of the Human Resource Development Plan described in this plan, it is desirable to develop an action plan, including a timeline, that details the actual roles to be played by each relevant department and the specific actions to be taken. Since it will require some time to strengthen the capacity of the HRD Section as described in the previous section, a task force team should be set up within PPWSA to develop the action plan.

10.5.3 Implementation Schedule

(1) Training Courses

1) Planning and Implementation of Training

The annual training plan is formulated by Admin & Human Resources Department and is implemented according to the plan, which includes internal training in which PPWSA staff are instructors on SOPs, etc., and external training in which external lecturers are invited or staff are sent to external training courses.

PPWSA also has opportunities to send staff to training and seminars outside the country every year, upon invitation. ***Table 10.5-3*** shows the results of internal and external training courses and the number of participants in recent years. As ***Table 10.5-3*** shows, there is a solid experience in managing training courses both a) within PPWSA and b) externally, with a total of more than 20 training courses managed annually.

Table 10.5-3 Implementation Records of Training Courses

Year	2016		2017		2018		2019	
Trainings	Courses	Participants	Courses	Participants	Courses	Participants	Courses	Participants
a) Courses in PPWSA	17	1095	17	1022	11	490	15	697
b) External courses (Cambodia)	5	73	10	181	12	292	7	134
c) Trainings and seminars abroad	12	33	12	19	8	15	7	14

Source: Summarized based on PPWSA data

The principles for the implementation of the training program described in ***Section 10.4.1 Training***

Program are shown below.

- ✓ Training by staff level should be conducted annually so that all eligible staff can attend.
- ✓ Skill based trainings are conducted periodically according to the number of targeted staff as a standard training catalogue.
- ✓ Specific trainings should be implemented based on the long list in ***Table 10.4-2*** depending on their availability. For gathering information on external training and seminars to be held, each department should cooperate with Admin. & HR Department.
- ✓ To grasp training needs, the existing personnel evaluation system should be used to identify areas where each staff needs to develop their skills. Periodically, this information should be consolidated to confirm and update training needs and reflect them in the training plan.
- ✓ Ensure that younger staff, regardless of their job title, can participate in at least one training courses per year, any of which is relevant to their work.

  [Example] 1st year - new staff training (training by level), SOP training (training by duty); 2nd year - Excel training (skill based training); 3rd year - English training (skill based training), SOP training (training by duty); 4th year - young staff training (training by level); 5th year - Presentation skills training (skill based training)
- ✓ Trainers should develop and secure the next generation of trainers while appointing training assistants to prepare training materials and take charge of some of the training sessions.
- ✓ Promote understanding of the importance of investing in human resources and training by informing training participants of the costs of training, etc.
- ✓ In addition to the current evaluation at the end of each training course, the effectiveness of the training should be assessed at the time of personnel review to determine whether training effectiveness has contributed to work improvement and whether new training is needed, and report from each department to HRD Section.
- ✓ In order to implement effective training, it is also necessary to strengthen the training management capacity of HRD Section. HRD Section will be strengthened by gradually increasing the number of annual training courses. The proposals to strengthen the implementation system are presented in Section ***10.5.2(1)***.

2) Regular Courses

The training courses that are considered necessary by 2030 are presented in ***Section 10.4.1***. In this section, the implementation schedule is proposed for each type of training. ***Table 10.5-4*** below shows the implementation schedule for training courses conducted regularly within PPWSA (including courses for which external instructors are invited).

Table 10.5-4 Implementation Schedule of Regular Training Courses

Training courses	Days /time	Persons /time	Times of implementation (times/year)								
			2022	2023	2024	2025	2026	2027	2028	2029	2030
I. Training by level											
1) New staff training (group training)	5	35	3	3	4	4	4	4	4	4	4
2) Young staff training (group training)	5	35	3	3	2	2	2	2	2	2	3
3) Basic management training (group training)	5	35	1	1	1	1	1	2	1	2	1
II. Skill based training											
1) Basic skills for young staff											
a) Basic business skill											
- Administration and Secretary work	2	50	1			1			1		
- OPERACY (soft skill/management skill)	3	50		1			1			1	
- Communication Skill; Negotiation skill, art of persuasion	2	50			1			1			1
- Meeting Minute, Reporting, documentation skills	2	50	1			1			1		
- Presentation Skill	2	50		1		1		1		1	
- leading the meeting	1	50			1			1			1
b) Basic skills for site work	3	30	1				1		1		
c) Basic computer skill											
- Microsoft Excel	5	20	1	1		1	1		1	1	1
- Microsoft Excel (Advance)	3	20			1			1			1

- Microsoft Power Point	5	20		1				1			1
- Microsoft Power Point (Advance)	3	20				1			1		
- Microsoft Access	5	20		1			1			1	
- GIS Data Input	5	20			1			1			1
- KIS Application (software)	5	50				1				1	
d) English											
- English	20	25	1	1	1	1	1	1	1	1	1
- English (Speaking/communication skill)	15	25		1			1			1	
- English (Official Doc. Correspondence)	15	25			1			1			1
2) Basic skills on management											
Management and Leadership	3	30	1				1			1	
Human Resource Management	3	30		1			1			1	
Facilitation skills for managers, trainers	3	30			1				1		
Negotiation and Conflict Resolution Techniques	2	30				1			1		
Management and Planning	5	30		1			1			1	
Results Based Program Monitoring & Evaluation	3	30			1			1			1
Statistic for Analysis	5	30	1				1				1
Project Management	5	30		1				1			1
Contract Management	3	30			1				1		
Foundation of accounting and finance	5	30	1				1				1
Asset management; data and Inventory Management	3	30		1				1			
Creativity, Design Thinking, and Innovation for Business	3	30			1					1	
III. Specific training by duty											
A Internal training within PPWSA											
1 Annual training on SOP (continued)	3	60	4	5	5	5	5	5	5	5	5
2 Management and Operation of Water Treatment Plant	5	60	1	1		1	1		1	1	
3 Basics on Water process and water quality management for WTP operators	3	60		1		1		1		1	
4 Knowledge and management of O&M of WTP facilities	3	15	1		1		1			1	
5 Knowledge and management of O&M of network facilities	3	15				1			1		
6 Maintenance of automation facilities/equipment, electronic, WTP	4	15			1			1			1
7 Maintenance of automation facilities/equipment, electronic, network	4	15	1				1			1	
8 General Knowledge on equipment/material being used in Waterworks	2	30		1					1		
9 Reporting on "verification of Customer Payment" (Ratio, SOP)	3	60	1				1				1
10 Skill of usage and maintenance of water meter of size of 80mm and over	3	60			1			1			
11 IT Risk Management	2	60	1			1			1		
12 Trainings of trainer	3	39	1		1			1			1
Total training courses in a year			25	25	26	25	25	27	27	27	28
Total training participants in a year			980	1005	975	1055	965	1075	1055	1040	1035

Source: JICA Data Collection Survey Team

3) External Training (Implemented Upon Availability)

As mentioned in ***Section 10.4.1(3)***, external training courses (corresponding to Category B in the table below) are held irregularly, and only a few courses can be implemented as planned. These courses should be referred to as a long list from time to time, and be implemented on opportunities when high-priority courses are held.

As for the specific courses in Category C and the master's courses listed as Category D, it is difficult to implement them with the resources available in Cambodia, so the utilization of development partners will be considered.

Table 10.5-5 Training Subjects and Implementation Schedule of External Training

No.	Training course /subjects	No. of Participants /time	2021 -2024	2025 -2027	2028 -2030
B	**Training mainly by outside resources (trainers/institutes) in Cambodia**				
13	3D Max	15	1		1
14	AutoCAD 2D & 3D	15	1	1	1
15	Google Sketch Up	15		1	
16	Microsoft Quick Book	15			1
17	Microsoft Project	15	1		
18	QGIS	15			1
19	Legal Skill	5		1	
20	Inspection Procedure	5	1		
21	Legislation	5		1	
22	Foundation of Inspection Work	5		1	
23	Public Administration	3		1	
24	Advanced Administration and Secretariat	3			1
25	Public Relation/ Communication with public	3		1	
26	Occupational Safety and Health	2	1		
27	Compliance	7	1		
28	Training Management and Evaluation	3		1	
29	Knowledge management/sharing	3			1
30	HR Development in an Institution (advance)	3	1		
31	Training Need Analysis (TNA)	3		1	
32	Auditing Skill	3	1		
33	Risk Management	5	1		1
34	Corporate Governance Auditing	3			1
35	Quality Management System Auditing	5		1	
36	Project Appraisal	10		1	
37	Advance Budget Planning & management	5			1
38	Long term planning and analysis (for finance)	5	1		1
39	Taxation Regulation Update	5	1		
40	Basics on IFRSs of Cambodia	5	1		
41	Update on IFRSs of Cambodia	3			1
42	Financial report design on Navision	3	1		
43	Customer Management and Service	5	1		
44	Public Relation Strategies	3		1	
45	Database Administrator	5			1
46	Firewall Security	3	1		
47	Machine learning	5		1	
48	Mobile App Development	3		1	
49	Programming: database language (SAMs by MS)	10	1		
50	Software project management	5			1
51	Comprehensive Cyber Security	5	1		
52	Visualization of software system	5			1
C	**Training mainly by trainings abroad or invited foreign experts**				
53	Operation Manual of Water Supply Apparatus				1
54	Infrastructure Development and Management			1	
55	Environmental and Social Safeguards				1
56	Financial Project / Analysis		1		
57	Common Procedure for Project Management, Procurement, Finance			1	
58	Training for User of IT System for Public Finance Management			1	
59	Hydraulic modelling, Data GIS Management, Water Gems		1		
60	Advance WaterGEMS		1		
61	Autodesk Revit (Structure, BIM Quantification and MEP Plumbing)		1		
62	ISO/IEC 17025:2017 Quality Management System Risk Management and Auditing		1		
63	Laboratory Management and Internal Audit		1		
64	Management of Testing Equipment and Chemical Waste for lab			1	
65	New Technology and Innovation			1	
66	Water Quality Equipment Operation and Maintenance				
67	Water Quality Management, Water Safety Plan		1		
68	Water quality modelling in pipe			1	
69	New technologies and strategic management for NRW reduction		1		
70	Catchment management and Environmental conservation			1	
71	Asset Management for maintenance		1		

No.	Training course /subjects	No. of Participants /time	2021 -2024	2025 -2027	2028 -2030
72	Efficient Water Distribution system/Pump Operation		1		
73	Quality Management Course (Quality survey and Quality Control)			1	
74	Pipe installation and Construction site management			1	
75	Pipe Hydraulic Calculation		1		
76	Warehouse Stock Management System		1		
D	**Master degree course**				
77	Civil Engineering	4	2	1	1
78	Management of Technology (application and evaluation)	3	1	1	1
79	Water resource	2		1	1
80	Water supply management	4	2	1	1

Source: JICA Data Collection Survey Team

(2) Other Measures

Table 10.5-6 Other Measures and Implementation

Measures/actions	Responsibilities to implement	2021-2024	2025-2027	2028-2030
Promotion of OJT				
Recording OJT: Every office starts recording OJT using the unified format which is to be defined by HRD Section	Each office	→	- - →	- - →
Developing OJT reference handbook: compile referential handbooks including applicable practices such as OJT records and good practices.	Admin & HR Dept/ resource managers		→	
Developing OJT instructor: Organize workshop targeting section chiefs to promote their understanding and skills for OJT with utilizing the OJT referential handbook in order to promote OJT in every office.	Admin & HR Dept /every office		→	→
Enhancement of knowledge-sharing				
Consider how to materialize the knowledge-sharing such as internal learning sessions and include the implementation schedule in annual business plan of each office.	Every office	→	- - →	- - →
Monitor the progress of each office, and share good practices among offies	Admin & HR Dept		→	→
Encouragement of self-development				
Establish a support system for active participation of staff in external seminars and events (establish a framework for participation opportunities, expenditures, and encouragement).	Admin & HR Dept		→	
Strengthen incentive systems: Reflect self-development activities and results in personnel evaluation and promotion systems.	Admin & HR Dept		→	
Strengthen resources for self-development: Improve access to resources within PPWSA, collaboration with external organizations, etc.	Admin & HR Dept			→
Intensive actions for future management				
Formulation of succession plan	Executives and senior officers (supported and monitored by Admin & HR Dept)	→		
Selection of candidates, and identify the field to be developed of each candidate		→		
Enhance capacity development while delegating more authority to lower-level positions		→	→	→
Help candidates develop and implement business plans		→	→	→
Clarify expertise and secure staff in each field				
Identify skill sets that should be acquired as specialized personnel in each field	Every department (supported and monitored the progress by Admin & HR Dept)		→	
Share the knowledge of experienced staff (study sessions, video archives, etc.)		→		
Contracting with retirees to provide technical advisory instructions		→		
Select candidates for master's degree to secure core staff in the specific field			→	→
Clarify the field for which "Expert staff" to be established.	Admin & HR Dept (consulted with each department)		→	
Appoint highly specialized staff as "Expert staff"				→

Source: JICA Data Collection Survey Team

10.5.4 The Effectiveness and Monitoring of Human Resource Development

In order to evaluate whether the issues indicated in ***Section 10.2 Current Situation of Human Resource Development*** are being improved through the implementation of each measure, the main indicators should be regularly monitored to confirm their effectiveness and impact on the business.

The main monitoring items, its current situation and target values are proposed below.

The current major style of training is in the form of a limited number of courses, mainly SOPs, conducted by a large number of people, resulting in a large number of training hours per person. Hereafter, in addition to the current style, a variety and practical of training courses, including specialized fields and skills required for duties, will be provided only to the designated staff who immediately need them; thereby decreasing the training time per staff but enabling individual staff to focus on the training contents directly related to their duties.

Table 10.5-7 Indicators to Monitor Human Resource Development Measures

Monitoring indicators	Present	2024	2027	2030
1. Training hours per staff per year （Internal training in PPWSA	244 hours (in 2019)	25 hours	24 hours	20 hours
2. Average of training participants number per course (Internal training in PPWSA)	64 people	36 persons	39 persons	36 persons
3. Number of specific training courses	13 courses	19 courses	17 courses	13 courses
4. Ratio of providing new staff training (training participants / all new staff)	N/A	100 % (82 persons)	100 % (130 persons)	100 % (130 persons)
5. Number of developed OJT instructors	N/A	-	30 persons (1 each in 75% of targeted offices)*	45 persons
6. Ratio of offices implementing knowledge-sharing activities	N/A	65%	70%	80%
7. Number of succession plans, number of its target (candidates for future executives)	N/A	30 persons (2 candidates in 50% of targeted offices)*	35 persons (2 candidates in 60 % of targeted offices)*	50 persons （3 candidates in 60 % of targeted offices)*
8. Number of “Expert Staff”	N/A	-	24 persons (20 % of staff of 50 years and older)*	48 persons

*Note: The formula was used as a reference for setting realistic target values, and the numbers in the formula do not imply a target.

In addition, in order to confirm the effectiveness of human resource development at the individual level, it is proposed to utilize personnel evaluations. PPWSA conducts personnel evaluations quarterly, and for example, the following categories are evaluated: compliance with regulations, work attitude, work performance, 5S, and social skills. One of the items of this “work performance” is “ability improvement” which is possible for a supervisor to confirm the training participation of individual staff and their reflection in subsequent work improvement, and propose the next necessary training of them to HRD Section.

CHAPTER 11 PROJECT COST

11.1 CONDITIONS FOR PROJECT COST ESTIMATION

11.1.1 Assumptions

The conditions used for estimation of project cost are shown in ***Table 11.1.1***.

Table 11.1.1 Conditions for Project Cost Estimation

Item	Calculation Conditions
Project cost components	The Project Cost includes the following: Construction Cost Consulting Cost Contingency Budget PPWSA Project Management Cost Price Escalation Note: Other costs related to the Project and Price Escalation are not included in the Project Cost and examined in ***Chapter 12***.
Project Cost	Calculation conditions
Construction Cost	Construction cost will be calculated on quantity survey with October, 2020 as the reference year.
Consulting Cost	Estimated as 6% of construction cost (10% for Nirodh III, Koh Norea and Phum Prek I Projects considering the possibility to be implemented under Japanese Yen Loan)
Contingency Budget	Estimated as 5% of construction cost Estimated as 5% of consulting cost
PPWSA Project Management Cost	Estimated as 1% of construction cost, consulting cost and contingency budget

Source: JICA Data Collection Survey Team

11.1.2 Estimation of Construction Costs

(1) Water Intake and Treatment Facilities

1) Review of Past Construction Costs

(a) Estimation of Unit Cost of Water Intake and Treatment Facility Construction

The unit construction cost of 2021 was calculated by adding the rate of price increase of 3% per year to past water facility development works implemented by PPWSA from the year of construction to present day.

Table 11-1.2 shows the construction costs for water intake and water purification facilities.

Table 11.1.2 Unit Construction Cost of Intake and WTP Facilities

Project	Planned Production Capacity (m^3/day)	Construction Year	Construction Cost (USD)	Construction Cost (USD/m^3)	Price Escalation Factor	Unit Construction Cost (USD/m^3) (as of 2021)
Chroy Changvar (Phase II)	65,000	2009	11,417,564	173.06	1.43	251.19
Nirodh (Phase I)	130,000	2013	53,715,706	280.49	1.27	524.77
Nirodh (Phase II)	130,000	2016	27,367,943	163.51	1.16	244.21
Chamcar Mon	52,000	2019	15,964,800	307.01	1.07	328.50
Bakheng (Phase I)	195,000	2023	57,112,500	401.26	1.00	292.89
Average Construction Cost						328.31

Source: JICA Data Collection Survey Team

(b) Estimation of Unit Cost of Wastewater Treatment Facilities

Unit construction cost for the wastewater treatment facility was calculated based on the "Construction Cost Estimation Sample" (***Table 11-1.3***) of the "Guide for calculating facility renewal costs related to the reconstruction of water supply projects (December 2011)" issued by the Ministry of Health, Labour and Welfare of Japan.

According to the guide, if the treatment capacity of the facility is 100,00 m^3/day, the unit construction cost will be 150 USD/m^3 from the following equation:

JPY 1,550,000,000 / 110 (USD1 = JPY110) / 100,000 m^3/day = USD140.91 /m^3/day

The inflation rate is not considered here as it has been low (about 0.5%) for the past 10 years from 2011 to 2021. In addition, since the labor unit price and civil engineering equipment unit construction cost in Cambodia are lower than in Japan, and a price correction of 70% of the Japanese price is used as a regional correction for the calculation. The result is a unit construction price of 100 USD/m^3.

Table 11.1.3 Construction Cost of Sewage Pont and Sludge Pond

	Work Type	Treatment Capacity (m^3/day)					Notes
		1,000	5,000	10,000	50,000	100,000	
Effluent basin, sludge basin	Civil	5	12	21	93	183	Direct foundation
	Mechanical	30	32	34	50	70	
	Electric	35	36	38	50	65	
	Total	70	80	93	193	318	
	Work Type	**Treatment Capacity (m^3/day)**					**Notes**
		1,000	**5,000**	**10,000**	**50,000**	**100,000**	
Thickening tank	Civil	67	69	72	96	126	Direct foundation
	Mechanical	82	83	85	97	112	
	Electric	62	62	62	62	62	
	Total	211	214	219	255	300	
	Work Type	**Treatment Capacity (m^3/day)**					**Notes**
		1,000	**5,000**	**10,000**	**50,000**	**100,000**	
Mechanical Dewatering facility	Civil	47	54	63	130	213	Direct foundation
	Mechanical	198	213	232	384	574	
	Electric	105	107	109	125	145	
	Total	351	374	403	638	932	
Total		**632**	**668**	**715**	**1,086**	**1,550**	

Source: Guide for Calculating facility renewal costs related to restructuring water supply operations (December, 2011)

(c) Unit Cost of Water Intake and Treatment Facilities

The unit construction cost of water intake facilities and WTPs will be 350 USD/m^3 This is the average unit construction cost of such facilities

2) Construction Cost of Water Intake and Treatment Facilities

Table 11-1.4 outlines the construction costs of water intake and WTP facilities.

Table 11.1.4 Construction Cost of Intake and Treatment Facilities

Project	Component	Planned Production Capacity (m^3/day)	Construction unit cost (USD/m^3)	Construction Cost (1,000USD)	Notes
Immediate Period Stage 1					
Bakheng Phase I	Intake	390,000			Included in WTP construction cost
	Raw water Transmission	390,000		4,547	D1,800mm, L=1040m
	WTP	195,000		571,120	
			Total	575,667	

Project	Component	Planned Production Capacity (m^3/day)	Construction unit cost (USD/m^3)	Construction Cost (1,000USD)	Notes
Bakheng Phase II	Intake				Constructed in Phase I
	Raw water Transmission				Constructed in Phase I
	WTP	195,000		35,268	
			Total		
Immediate Period Stage 2					
Ta Khmao	Intake	30,000			Currently being implemented by Japanese Grant Aid Project
	Raw water Transmission	30,000			
	WTP	30,000			
			Total		
Intermediate Period Stage 1					
Phum Prek Phase III	Intake	45,000			Under planning for Japanese Grant Aid Project
	Raw water Transmission	45,000		5,000	D800, L=2,000m Open cut & Pipe Jacking method
	WTP	45,000			Under planning for Japanese Grant Aid Project
			Total	**5,000**	
Intermediate Period Stage 2					
Bakheng Phase III	Intake	195,000			Included in WTP construction cost
	Raw water Transmission	195,000	16,000	8,800	
	WTP	195,000	350	68,250	
	Mechanical Sludge Treatment Facilities	585,000	100	58,500	Sludge treatment facilities for Phase I and II will be examined separately.
			Total	**135,550**	
Ultimate Period Stage 1					
Nirodh Phase III	Intake	130,000			Included in WTP construction cost
	Raw water Transmission	130,000	20,000	50,000	D1,600mm, L=2,500m, Pipe-jacking method
	WTP	130,000	350	45,500	
	Mechanical Sludge Treatment Facilities	390,000	100	39,000	Sludge treatment facilities for Phase I and II will be examined separately.
			Total	**134,500**	
Koh Norea	Intake	150,000			Included in WTP construction cost
	Raw water Transmission	150,000	18,000	18,000	D1,350mm, L=1,000m, Pipe-jacking method
	WTP	150,000	350	52,500	
	Mechanical Sludge Treatment Facilities	150,000	100	15,000	
			Total	**85,500**	
Reconstruction of Phum Prek Phase I	Intake	150,000		8,000	New construction
	Raw water Transmission				
	WTP	100,000	525	52,500	Reconstruction of Phase I water

Project	Component	Planned Production Capacity (m³/day)	Construction unit cost (USD/m³)	Construction Cost (1,000USD)	Notes
					treatment facilities (Unit cost includes the cost of demolition of existing facilities)
	Comprehensive Monitoring and Management Center			8,000	
	Mechanical Sludge Treatment Facilities	195,000	100	19,500	Sludge treatment facilities for Phase II and III will be examined separately.
			Total	**88,000**	
Ultimate Period Stage 2					
Ta Mouk Phase I	Intake	400,000	100	40,000	Phase I, which in the future will include Phase II, is included in WTP construction cost.
	Raw water Transmission	400,000	22,000	55,000	D2,000mm, L=2,500m, Future Phase I is included
	WTP	200,000	350	70,000	
	Mechanical Sludge Treatment Facilities	200,000	100	20,000	
			Total	**185,000**	
Khsach Kanda	Intake	100,000			Included in WTP construction cost
	Raw water Transmission	100,000	24,397	24,397	
	WTP	100,000	350	35,000	
	Mechanical Sludge Treatment Facilities	100,000	100	10,000	
			Total	**69,397**	
New Airport City	Intake	30,000			Included in WTP construction cost
	Raw water Transmission	30,000	4,374	4,374	
	WTP	30,000	350	10,500	
	Mechanical Sludge Treatment Facilities	30,000	100	3,000	
			Total	**17,874**	
Ta Mouk Phase II	Intake				Constructed in Phase I
	Raw water Transmission				Constructed in Phase I
	WTP	200,000	350	70,000	
	Mechanical Sludge Treatment Facilities	200,000	100	20,000	
			Total	**90,000**	

Source: JICA Data Collection Survey Team

3) Operation and Maintenance Costs of Water Treatment Facilities

(2) Water Transmission and Distribution Lines

1) Unit Construction Costs of Water Transmission and Distribution Lines

Table 11-1.5 shows the calculation conditions for the unit construction cost of water pipes.

Table 11.1.5 Calculation Conditions for Water Pipes

Item	Contents
Construction Unit Cost	Construction unit cost is the total of pipe material cost and installation cost. Cost of tunnelling methods will be based on costs incurred in the Bakheng Phase I Project.
Pipe Material Cost	Pipe material cost will be based on the PPWSA "Data for Planning and Design of Unit Cost Pipe Laying" and include pipe material cost, backfill cost, and repaving cost.
Installation Cost	Installation cost will be estimated as 30% of pipe material cost.

Source: JICA Data Collection Survey Team

2) Construction Cost of Water Transmission and Distribution Lines

Table 11-1.6 shows the construction costs of transmission and distribution mains.

Table 11.1.6 Construction Costs of Transmission and Distribution Mains

	Diameter (mm)	Length (m)	Unit Rate (m/USD)	Construction Cost (1000 USD)	Remarks （Construction period）
Intermediate Period Stage 1					
Phum Prek Phase III					(2023-2026)
Transmission Mains	500	360	378	136	(2025)
Distribution Mains	300	38,889	208	8089	(2025)
	250	10,013	182	1822	(2025)
	225	18,095	129	2334	(2025)
	160	35,094	97	3404	(2025)
	110	45,364	45	2041	(2025)
	300	40,387	208	8401	(2026)
	250	4,098	182	746	(2026)
	225	12,199	129	1574	(2026)
	160	775	97	75	(2026)
	110	712	45	32	(2026)
Intermediate Period Stage 2					
Bakheng Phase III					(2025-2027)
Transmission Mains	1,200	300	2,251	675	(2026)
	1,000	3,600	1,921	6,916	(2026)
	600	800	437	350	(2026)
	500	9,500	378	3,591	(2026)
	400	24,600	250	6,150	(2026)
	300	27,100	208	5,637	(2027)
Distribution Mains	300	20,284	208	4,219	(2026)
	250	10,574	182	1,924	(2026)
	225	13,380	129	1,726	(2026)
	160	11,054	97	1,072	(2026)
	110	9,497	45	427	(2026)
	300	11,059	208	2,300	(2027)
	250	4,112	182	748	(2027)
	225	12,359	129	1,594	(2027)
	160	15,634	97	1,516	(2027)
	110	19,289	45	868	(2027)
Ultimate Period Stage 1					
Nirodh Phase III					(2026-2029)
Transmission Mains	1000	5,900	1,921	11,334	(2028)
	900	1,000	1,611	1,611	(2029)
	800	9,800	965	9,457	(2029)

	Diameter (mm)	Length (m)	Unit Rate (m/USD)	Construction Cost (1000 USD)	Remarks （Construction period）
	600	9,200	437	4,020	(2029)
	500	8,600	378	3,251	(2029)
	400	600	250	150	(2029)
	300	3,700	208	770	(2029)
	250	500	182	91	(2029)
Road Crossing 4	600	30	8,000	240	(2029)
Distribution Mains	300	23,384	208	4,864	(2028)
	225	10,473	129	1,351	(2028)
	160	2,240	97	217	(2028)
	110	2,663	45	120	(2028)
	300	17,830	208	3,709	(2029)
	250	2,265	182	412	(2029)
	225	8,299	129	1,071	(2029)
	160	11,944	97	1,159	(2029)
	110	14,896	45	670	(2029)
Koh Norea					(2026-2029)
Transmission Mains	1,600	17,000	4,652	79,084	(2028)
	1,400	3,900	2,898	11,302	(2028)
	1,200	5,200	2,251	11,705	(2028)
	600	1,100	437	481	(2029)
	500	1,000	378	378	(2029)
	400	300	250	75	(2029)
	300	100	208	21	(2029)
	250	900	182	164	(2029)
Bassac River crossing	1,600	500	20,000	10,000	(2028)
Prek Thnot River crossing	1,600	50	20,000	1,000	(2028)
Koh Norea Waterway Crossing	1,200	50	16,000	800	(2028)
Road Crossing 5	1,600	30	14,000	420	(2028)
Road Crossing 6	1,600	30	14,000	420	(2028)
Road Crossing 7	1,600	30	14,000	420	(2028)
Road Crossing 8	1,600	30	14,000	420	(2028)
Road Crossing 9	1,200	30	12,000	360	(2028)
Distribution Mains	300	15,134	208	3148	(2028)
	250	7,418	182	1350	(2028)
	225	4,040	129	521	(2028)
	160	6,541	97	634	(2028)
	110	1,853	45	83	(2028)
	300	9,332	208	1941	(2029)
	250	3,949	182	719	(2029)
	225	10,603	129	1368	(2029)
	160	19,071	97	1850	(2029)
	110	25,559	45	1150	(2029)
Ultimate Period Stage 2					
Ta Mouk Phase I					(2027-2030)
Transmission Mains	1,600	9,400	4,652	43,729	(2030)
	1,400	6,000	2,898	17,388	(2030)
	1,200	3,800	2,251	8,554	(2030)
	1,000	6,300	1,921	12,102	(2030)
	800	1,600	965	1,544	(2030)
	600	1,900	437	830	(2030)
	500	4,100	378	1,550	(2030)
	400	2,000	250	500	(2030)
Railway Crossing 1	1,600	20	14,000	280	(2030)
Railway Crossing 2	1,000	20	10,000	200	(2030)
Road Crossing 1	1,600	30	14,000	420	(2030)
Road Crossing 2	1,200	30	12,000	360	(2030)

	Diameter (mm)	Length (m)	Unit Rate (m/USD)	Construction Cost (1000 USD)	Remarks （Construction period）
Road Crossing 3	1,000	30	10,000	300	(2030)
Distribution Mains	300	67,920	208	14,127	(2030)
	250	2,230	182	406	(2030)
	225	7,240	129	934	(2030)
	160	13,420	97	1,302	(2030)
	110	16,010	45	720	(2030)
Khsach Kanda					(2028-2030)
Transmission Mains	1,200	200	2,251	450	(2030)
	1,000	500	1,921	961	(2030)
	600	200	437	87	(2030)
New Airport City					(2028-2030)
Transmission Mains	600	11,000	437	4,807	(2030)
Distribution Improvement and Rehabilitation	Pipe with a diameter of less than 100 mm			1,000	(2023)
				1,000	(2024)
				1,000	(2025)
				1,000	(2026)
				1,000	(2027)
				1,000	(2028)
				1,000	(2029)
				1,000	(2030)
	Customer Meter Replacement			540	(2023)
				540	(2024)
				540	(2025)
				540	(2026)
				972	(2027)
				675	(2028)
				972	(2029)
				702	(2030)

Source: JICA Data Collection Survey Team

11.2 PROJECT COST ESTIMATION

11.2.1 Phum Prek Phase III Project

Table 11.2.1 shows the estimated costs of the Phum Prek Phase III Project.

Table 11.2.1 Estimated Costs of the Phum Prek Phase III Project

Item		Cost (1000USD)	Remarks
INTERMEDIATE PERIOD Stage 1			
Phum Prek Phase III		**14,596**	Estimated completion: 2026
Construction Cost	Water Treatment Plant		Under planning for Japanese Grant Aid Project
	Raw Water Transmission Main	5,000	
	Transmission Main	136	
	Distribution Main	9,460	
PPWSA Project Management Cost	1% of the sum of construction cost, consulting cost, and contingency cost	146	

Source: JICA Data Collection Survey Team

11.2.2 Bakheng Phase III Project

Table 11.2.2 shows the estimated costs of the Bakheng Phase III Project.

Table 11.2.2 Estimated Costs of the Ta Khmao Project

Item		Cost (1000USD)	Remarks
INTERMEDIATE PERIOD Stage 2			
Bakheng Phase III		**186,692**	Estimated completion: 2027
Construction Cost	Water Treatment Plant	135,550	
	Transmission Main	23,324	
	Distribution Main	7,203	
Consulting Cost	6% of Construction Cost	9,965	
Contingency Budget	5% of the sum of construction cost and consulting cost	8,802	
PPWSA Project Management Cost	1% of the sum of construction cost, consulting cost, and contingency cost	1,848	

Source: JICA Data Collection Survey Team

11.2.3 Equipment Update of Chroy Changvar WTP

Table 11.2.3 shows the estimated costs of the Bakheng Phase III Project.

Table 11.2.3 Estimated Costs of the Chroy Changvar Project

Item		Cost (1000USD)	Remarks
INTERMEDIATE PERIOD Stage 2			
Chroy Changvar WTP		**22,483**	Estimated completion: 2027
Construction Cost	Update of the Equipment	20,000	
Consulting Cost	6% of Construction Cost	1,200	
Contingency Budget	5% of the sum of construction cost and consulting cost	1,060	
PPWSA Project Management Cost	1% of the sum of construction cost, consulting cost, and contingency cost	223	

Source: JICA Data Collection Survey Team

11.2.4 Nirodh Phase III Project

Table 11.2.4 shows the estimated costs of the Nirodh Phase III Project.

Table 11.2.4 Estimated Costs of the Nirodh Phase III Project

Item		Cost (1000USD)	Remarks
ULTIMATE PERIOD Stage 1			
Nirodh Phase III		**198,327**	Estimated completion: 2029
Construction Cost	Water Treatment Plant	134,500	
	Transmission Main	30,924	
	Distribution Main	4,588	
Consulting Cost	10% of Construction Cost	17,001	
Contingency Budget	5% of the sum of construction cost and consulting cost	9,351	
PPWSA Project Management Cost	2% of the sum of consulting cost and contingency cost	1,964	

Source: JICA Data Collection Survey Team

11.2.5 Koh Norea Project

The estimated costs of the Koh Norea Project are shown in ***Table 11.2.5***.

Table 11.2.5 Estimated Costs of the Koh Norea Project

Item		Cost (1000USD)	Remarks
ULTIMATE PERIOD Stage 1			
Koh Norea		**242,824**	Estimated completion: 2029
Construction Cost	Water Treatment Plant	85,500	
	Transmission Main	117,050	
	Distribution Main	5,606	
Consulting Cost	10% of Construction Cost	20,816	
Contingency Budget	5% of the sum of construction cost and consulting cost	11,449	
PPWSA Project Management Cost	1% of the sum of construction cost, consulting cost, and contingency cost	2,404	

Source: JICA Data Collection Survey Team

11.2.6 Reconstruction of Phum Prek Phase I Project

Table 11.2.6 shows the estimated costs of the Reconstruction of Phum Prek Phase I Project.

Table 11.2.6 Estimated Costs of the Reconstruction of Phum Prek Phase I Project

Item		Cost (1000USD)	Remarks
ULTIMATE PERIOD Stage 1			
Reconstruction of Phum Prek Phase I		**102,656**	Estimated completion: 2031
Construction Cost	Reconstruction of Phum Prek Phase I WTP	88,000	Including construction new raw water intake facility and comprehensive monitoring and management centre
Consulting Cost	10% of Construction Cost	8,800	
Contingency Budget	5% of the sum of construction cost and consulting cost	4,840	
PPWSA Project Management Cost	1% of the sum of construction cost, consulting cost, and contingency cost	1,016	

Source: JICA Data Collection Survey Team

11.2.7 Ta Mouk Phase I Project

Table 11.2.7 shows the estimated costs of the Ta Mouk Phase I Project.

Table 11.2.7 Estimated Costs of the Ta Mouk Phase I Project

Item		Cost (1000USD)	Remarks
ULTIMATE PERIOD Stage 2			
Ta Mouk Phase I		**314,137**	Estimated completion: 2030
Construction Cost	Water Treatment Plant	185,000	
	Transmission Main	87,757	
	Distribution Main	6,692	
Consulting Cost	6% of Construction Cost	16,767	
Contingency Budget	5% of the sum of construction cost and consulting cost	14,811	
PPWSA Project Management Cost	1% of the sum of construction cost, consulting cost, and contingency cost	3,110	

Source: JICA Data Collection Survey Team

11.2.8 Khsach Kandal Project

Table 11.2.8 shows the estimated cost of the Khsach Kanda Project.

Table 11.2.8 Estimated Costs of the Khsach Kanda Project

Item		Cost (1000USD)	Remarks
ULTIMATE PERIOD Stage 2			
Khsach Kandal		**79,695**	Estimated completion: 2030
Construction Cost	Water Treatment Plant	69,397	
	Transmission Main	1,498	
Consulting Cost	6% of Construction Cost	4,254	
Contingency Budget	5% of the sum of construction cost and consulting cost	3,757	
PPWSA Project Management Cost	1% of the sum of construction cost, consulting cost, and contingency cost	789	

Source: JICA Data Collection Survey Team

11.2.9 New Airport City Project

Table 11.2.9 shows the estimated cost of the New Airport City Project.

Table 11.2.9 Estimated Costs of the New Airport City Project

Item		Cost (1000USD)	Remarks
ULTIMATE PERIOD Stage 2			
New Airport City		**25,496**	Estimated completion: 2030
Construction Cost	Water Treatment Plant	17,874	
	Transmission Main	4,807	
Consulting Cost	6% of Construction Cost	1,361	
Contingency Budget	5% of the sum of construction cost and consulting cost	1,202	
PPWSA Project Management Cost	1% of the sum of construction cost, consulting cost, and contingency cost	252	

Source: JICA Data Collection Survey Team

11.2.10 Ta Mouk Phase II Project

Table 11.2.10 shows the estimated costs of the Ta Mouk Phase II Project.

Table 11.2.10 Estimated Costs of the Ta Mouk Phase II Project

Item		Cost (1000USD)	Remarks
ULTIMATE PERIOD Stage 2			
Ta Mouk Phase II		**174,240**	Estimated completion: 2031
Construction Cost	Water Treatment Plant	90,000	
	Transmission Main	65,000	
Consulting Cost	6% of Construction Cost	9,300	
Contingency Budget	5% of the sum of construction cost and consulting cost	8,215	
PPWSA Project Management Cost	1% of the sum of construction cost, consulting cost, and contingency cost	1,725	

Source: JICA Data Collection Survey Team

11.3 SUMMARY OF PROJECT COST

Table 11.3.1shows the summary of project cost in case water treatment plant installed mechanical sludge treatment facilities and ***Table 11.3.2*** shows the summary of project cost without mechanical sludge treatment facilities.

Table 11.3.3 shows summary of required electric power for distribution pumps in the water treatment plants.

Table 11.3.1 Summary of Project Cost

Unit: 1000USD

No	WTP Scheme	Year of Completion	Development Cost			Administration Cost		Contingencies	Project Cost
			Production System	Transmission / Distribution System	Total Development Cost	Supervisory Works	PPWSA Management Cost		
1	Phun Prek Phase III	2026	5,000	9,596	14,596		146		14,742
2	Bakheng Phase III	2027	135,550	30,527	166,077	9,965	1,848	8,802	186,692
3	Equipment Update of Chroy Changvar	2027	20,000	0	20,000	1,200	223	1,060	22,483
4	Nirodh Phase III	2029	134,500	35,512	170,012	17,001	1,964	9,351	198,327
5	Koh Norea	2029	85,500	122,656	208,156	20,816	2,404	11,449	242,824
6	Ta Mouk Phase I	2030	185,000	94,449	279,449	16,767	3,110	14,811	314,137
7	Khsach Kandal	2030	69,397	1,498	70,895	4,254	789	3,757	79,695
8	New Airport City	2030	17,874	4,807	22,681	1,361	252	1,202	25,496
9	Reconstruction of Phum Prek Phase I	2031	88,000	0	88,000	8,800	1,016	4,840	102,656
10	Ta Mouk Phase II	2031	90,000	65,000	155,000	9,300	1,725	8,215	174,240
		Total	**830,821**	**364,045**	**1,194,866**	**89,463**	**13,478**	**63,487**	**1,361,294**

Source: JICA Data Collection Survey Team

Table 11.3.2 Summary of Project Cost (in case WTP without Mechanical Sludge Treatment Facilities)

Unit: 1000USD

No	WTP Scheme	Year of Completion	Development Cost			Administration Cost		Contingencies	Project Cost
			Production System	Transmission / Distribution System	Total Development Cost	Supervisory Works	PPWSA Management Cost		
1	Phun Prek Phase III	2026	5,000	9,596	14,596		146		14,742
2	Bakheng Phase III	2027	77,050	30,527	107,577	6,455	1,197	5,702	120,931
3	Equipment Update of Chroy Changvar	2027	20,000	0	20,000	1,200	223	1,060	22,483
4	Nirodh Phase III	2029	95,500	35,512	131,012	13,101	1,513	7,206	152,832
5	Koh Norea	2029	70,500	122,656	193,156	19,316	2,231	10,624	225,326
6	Ta Mouk Phase I	2030	165,000	94,449	259,449	15,567	2,888	13,751	291,654
7	Khsach Kandal	2030	59,397	1,498	60,895	3,654	678	3,227	68,454
8	New Airport City	2030	14,874	4,807	19,681	1,181	219	1,043	22,124
9	Reconstruction of Phum Prek Phase I	2031	68,500	0	68,500	6,850	791	3,768	79,909
10	Ta Mouk Phase II	2031	70,000	65,000	135,000	8,100	1,503	7,155	151,758
		Total	**645,821**	**364,045**	**1,009,866**	**75,423**	**11,388**	**53,535**	**1,150,212**

Source: JICA Data Collection Survey Team

Table 11.3.3 Summary of Required Electric Power for Distribution Pumps in the Water Treatment Plants

WTP	Capacity	Number of Pump	Distribution Pump Capacity per Pump			Pump Lift	Required Power per Pump	Required Total Power		
	m3/day		m^3/day	m^3/h	m^3/min	m	kWH	kWH	kWH/m^3	kWH/year
Phum Prek WTP	195,000	12	16,250	677	11.28	36	101	1,214	0.149	10,634,731
Chamcar Mon WTP	52,000	4	13,000	542	9.03	37	83	333	0.154	2,914,704
Chroy Changvar WTP	130,000	8	16,250	677	11.28	38	107	854	0.158	7,483,700
Nirodh WTP I + II	260,000	12	21,667	903	15.05	39	146	1,754	0.162	15,361,278
Bakheng WTP I & II	390,000	13	30,000	1,250	20.83	40	208	2,698	0.166	23,632,736
Ta Khmao WTP	30,000	3	10,000	417	6.94	40	69	208	0.166	1,817,903
Bakheng WTP III	195,000	12	16,250	677	11.28	41	115	1,383	0.170	12,111,777
Koh Norea WTP	150,000	12	12,500	521	8.68	42	91	1,089	0.174	9,543,990
Nirodh WTP III	130,000	12	10,833	451	7.52	43	81	967	0.178	8,468,397
Ta Mouk WTP I	200,000	12	16,667	694	11.57	44	127	1,522	0.183	13,331,287
Ta Mouk WTP II	200,000	12	16,667	694	11.57	45	130	1,556	0.187	13,634,271
Khsach Kandal WTP	100,000	8	12,500	521	8.68	45	97	778	0.187	6,817,135
New Airport City WTP	30,000	3	10,000	417	6.94	46	80	239	0.191	2,090,588

CHAPTER 12 FINANCIAL STUDY

12.1 BACKGROUND AND OBJECTIVES OF THE STUDY

This survey has proposed a large-scale investment plan taking into account the further growth in demand. This section of the survey analyses the financial viability of the investment plan and impact on PPWSA's overall financials.

In particular this financial study focuses on the following:

1. Net present cost of water (NPCW) and financial internal rate of return (FIRR) of each proposed project
2. Financing options for the investment plan
3. Impact of the investment plan on PPWSA's financials

12.2 FINANCIAL REVIEW OF THE THIRD MASTERPLAN

The Third Masterplan analysed NPCW on different discount rates and FIRR on different water tariffs, for Bakheng WTPand Chamcar Mon WTP. The results are shown below.

Definitions of NPCW and FIRR:

- Net present cost of water (NPC) is defined by the Net Present Value of CAPEX and OPEX, divided by the Net Present Value of volumes produced.
- Financial internal rate of return (FIRR) is a rate at which net present value of a project equals to zero.

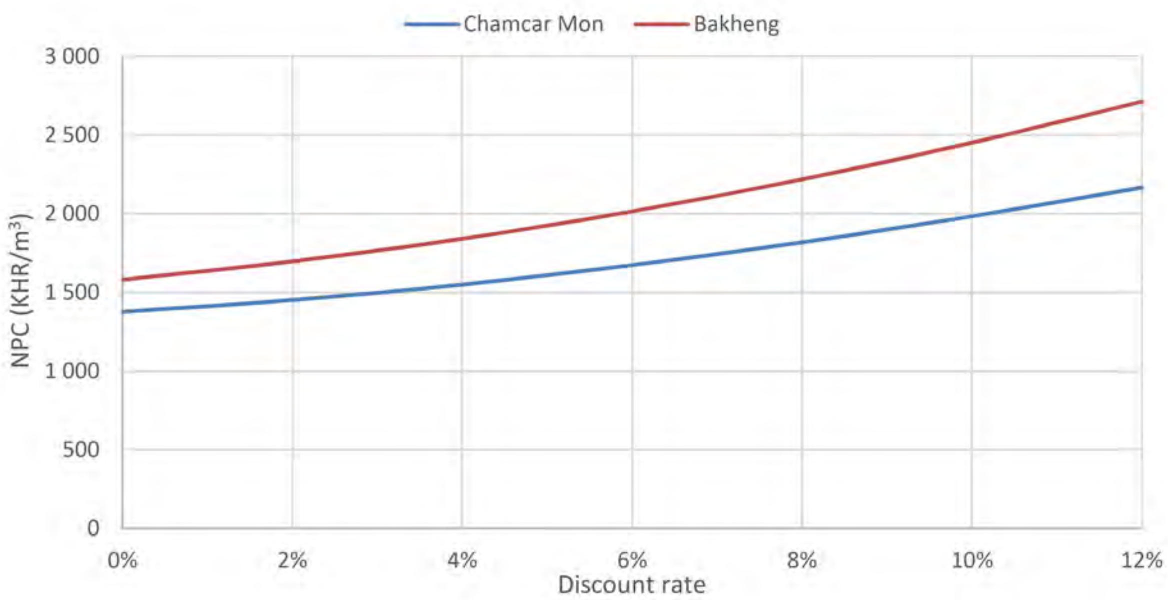


Figure 12.2.1 Net Present Cost of Water for Chamcar Mon and Bakheng WTP
Source: Third Master Plan (M/P2017)

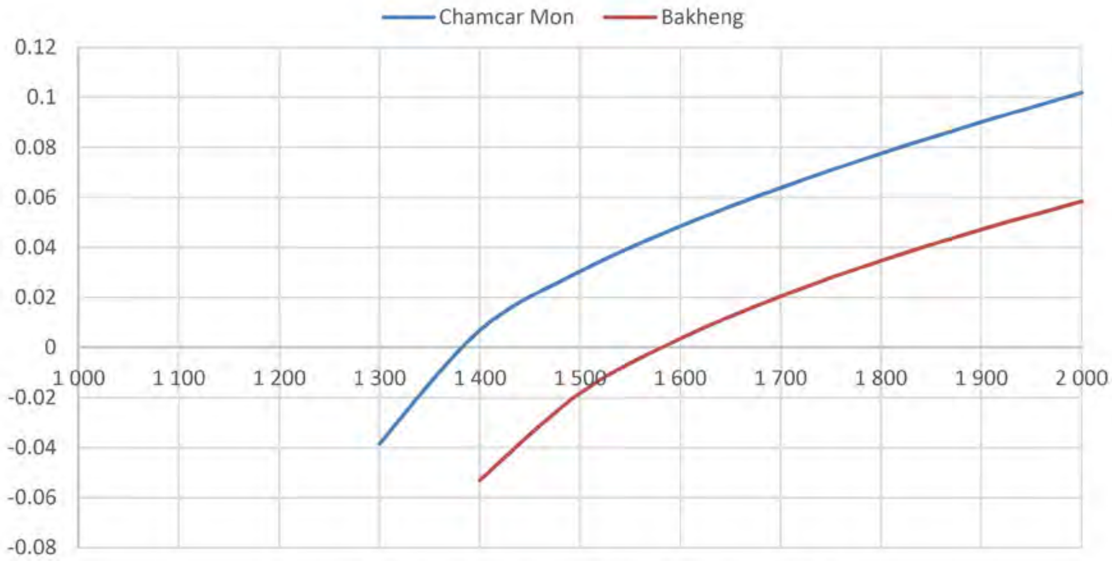


Figure 12.2.2 Financial Internal Rate of Return for Chamcar Mon and Bakheng WPF
Source: Third Master Plan (M/P2017)

Under the base case assumption at 5% discount rate, net present cost of water is calculated KHR1,609/m³ for Chamcar Mon and KHR1,924/m³ for Bakheng, both of which are much higher than the current water tariff. The Master Plan pointed out that microeconomic theory recommends pricing water at its marginal cost. Therefore, PPWSA should raise the water tariff to at lease KHR1,700/m³ as soon as practical. The Master Plan also provided financial modelling for PPWSA's overall finances and confirmed PPWSA will remain profitable and financially sound under the base case scenario in which water tariff increases gradually to KHR1,700/m³ by 2024.

12.3 REVIEW OF THE LATEST FINANCIAL FORECAST

PPWSA's latest financial forecast is summarized in the table below. PPWSA annually prepares and submits a financial plan to the board meeting for approval. The latest financial plan, which as submitted August 2021, is summarized in ***Table 12.3.1*** with comparison with the Master Plan.

Table 12.3.1 PPWSA's Latest Financial Forecast

PPWSA's Forecast as of August 2021

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	224,774	245,000	249,000	287,000	293,000	300,000	307,114	315,312	322,885	329,401	335,975
Water Tariff	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354
NRW Rate	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%	12%
Total Income	324,368	342,894	348,837	402,791	425,709	434,726	442,509	450,388	459,552	467,648	475,983
Total Expenses	144,379	155,305	164,171	182,701	192,926	198,627	205,661	212,385	219,348	226,061	232,555
Depreciation	50,402	59,336	58,479	57,688	109,425	133,708	131,640	129,448	127,260	125,149	122,978
Operating Profit	129,587	128,252	126,187	162,403	123,358	102,391	105,208	108,555	112,945	116,438	120,450
Net Profit	88,352	98,592	97,683	127,538	86,023	63,201	66,768	72,222	78,603	83,979	87,746
Net Margin	27.2%	28.8%	28.0%	31.7%	20.2%	14.5%	15.1%	16.0%	17.1%	18.0%	18.4%
Cash&ST Investments	118,155	100,892	70,460	78,484	60,473	95,043	192,004	266,504	315,726	368,385	433,863
Total Assets	1,864,618	2,271,236	2,716,438	3,101,499	3,086,531	3,086,915	3,148,628	3,188,825	3,204,502	3,223,933	3,216,336
Total Indebtedness	548,136	846,918	1,143,914	1,379,366	1,351,252	1,305,556	1,297,114	1,260,704	1,191,757	1,121,850	1,027,867
Equity	982,053	1,097,648	1,195,331	1,322,870	1,408,892	1,472,094	1,538,862	1,611,084	1,689,688	1,773,667	1,861,413
Current Ratio	1.3	1.5	1.3	1.4	1.6	2.0	2.2	2.3	2.5	2.7	3.0
DSCR	1.6	4.0	5.2	6.2	4.1	3.2	3.8	2.6	2.0	2.0	2.0
Net debt to EBITDA	2.3	4.0	5.8	5.9	5.5	5.1	4.7	4.2	3.6	3.1	2.4
Debt on Equity	55.8%	77.2%	95.7%	104.3%	95.9%	88.7%	84.3%	78.3%	70.5%	63.3%	55.2%

Maste Plan

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	240,131	255,890	269,660	283,641	295,556	307,926	318,282	326,486	334,064	340,585	347,162
Water Tariff	1,300	1,400	1,500	1,600	1,700	1,700	1,700	1,700	1,700	1,700	1,700
NRW Rate	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Total Income	328,085	372,548	416,479	464,109	511,281	531,231	546,064	555,560	566,364	575,706	585,236
Total Expenses	175,348	192,307	219,484	247,471	265,519	280,729	294,818	306,262	320,131	334,427	349,511
Depreciation	52,510	51,116	49,777	88,139	85,462	99,736	98,731	97,600	96,349	95,039	93,725
Operating Profit	100,227	129,125	147,218	128,499	160,301	150,766	152,515	151,698	149,884	146,240	142,000
Net Profit	69,453	87,414	97,190	76,835	97,200	88,996	93,902	97,543	100,658	102,402	103,269
Net Margin	21.2%	23.5%	23.3%	16.6%	19.0%	16.8%	17.2%	17.6%	17.8%	17.8%	17.6%
Cash&ST Investments	148,264	138,694	130,307	60,761	49,272	79,856	139,978	208,481	280,453	347,286	414,335
Total Assets	1,982,391	2,210,982	2,531,506	2,663,629	2,770,177	2,785,087	2,826,373	2,872,612	2,921,246	2,964,505	3,008,220
Total Indebtedness	701,370	828,285	1,027,027	1,114,444	1,140,318	1,057,861	985,527	915,494	843,796	784,930	725,232
Equity	998,887	1,072,410	1,152,118	1,209,515	1,306,715	1,395,710	1,489,613	1,587,156	1,687,814	1,770,084	1,852,873
Current Ratio	1.5	1.4	0.9	0.7	0.7	1.0	1.4	1.8	2.4	2.8	6.3
DSCR	2.2	2.5	2.6	1.5	1.9	1.5	1.7	1.8	1.9	2.1	2.1
Net debt to EBITDA	3.6	3.8	4.6	4.9	4.4	3.9	3.4	2.8	2.3	1.8	1.3
Debt on Equity	70.2%	77.2%	89.1%	92.1%	87.3%	75.8%	66.2%	57.7%	50.0%	44.3%	39.1%

Difference

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	-15,357	-10,890	-20,660	3,359	-2,556	-7,926	-11,168	-11,174	-11,179	-11,184	-11,187
Water Tariff	54	-46	-146	-246	-346	-346	-346	-346	-346	-346	-346
NRW Rate	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Total Income	-3,717	-29,654	-67,642	-61,318	-85,572	-96,505	-103,555	-105,172	-106,812	-108,058	-109,253
Total Expenses	-30,969	-37,002	-55,313	-64,770	-72,593	-82,102	-89,157	-93,877	-100,783	-108,366	-116,956
Depreciation	-2,108	8,220	8,702	-30,451	23,963	33,972	32,909	31,848	30,911	30,110	29,253
Operating Profit	29,360	-873	-21,031	33,904	-36,943	-48,375	-47,307	-43,143	-36,939	-29,802	-21,550
Net Profit	18,899	11,178	493	50,703	-11,177	-25,795	-27,134	-25,321	-22,055	-18,423	-15,523
Net Margin	6.1%	5.3%	4.7%	15.1%	1.2%	-2.2%	-2.1%	-1.5%	-0.7%	0.2%	0.8%
Cash&ST Investments	-30,109	-37,802	-59,847	17,723	11,201	15,187	52,026	58,023	35,273	21,099	19,528
Total Assets	-117,773	60,254	184,932	437,870	316,354	301,828	322,255	316,213	283,256	259,428	208,116
Total Indebtedness	-153,234	18,633	116,887	264,922	210,934	247,695	311,587	345,210	347,961	336,920	302,635
Equity	-16,834	25,238	43,213	113,355	102,177	76,384	49,249	23,928	1,874	3,583	8,540
Current Ratio	-0.2	0.0	0.4	0.7	0.9	1.0	0.9	0.5	0.1	-0.1	-3.3
DSCR	-0.6	1.5	2.6	4.7	2.2	1.7	2.1	0.8	0.1	-0.1	-0.1
Net debt to EBITDA	-1.3	0.2	1.2	1.0	1.1	1.2	1.3	1.4	1.3	1.3	1.1
Debt on Equity	-14.4%	0.0%	6.6%	12.2%	8.6%	12.9%	18.1%	20.6%	20.5%	19.0%	16.1%

Source: Third Master Plan (M/P2017)

Divergence from the Master Plan are outlined as follows:

- Long-term average tariff has been revised down from KHR1,700/m³ to KHR1,354/m³ because PPWSA has been profitable under the current water tariff and considers it difficult to gain approval of tariff increase to KHR1,700/m³.
- Long-term non-revenue water ratio has been revised up from 10% to 12%. PPWSA's historical record, the assumption for water demand in this survey, and the management goal are all 10%. But for the purposes of financial plan, it is assumed at 12% to be conservative taking into account further expansion of distribution network in the future.

- Long-term inflation rate has been revised down from 5% to 3% as IMF forecast has been revised down.

Even under the assumptions above (decrease in water tariff and increase in non-revenue water ratio), PPWSA remains profitable in the mid-term thanks to reduction in operating costs which partly resulted from change in inflation rate. It shall be noted, however, that the financial solvency would deteriorate and fail to comply with existing loan covenants such as net debt to EBITDA and PPWSA will not distribute dividend to the shareholders for the time being.

12.4 ASSUMPTIONS FOR THE FINANCIAL ANALYSIS

CAPEX and OPEX assumptions used in this financial analysis are summarized in ***Table 12.4.1*** . CAPEX are those stipulated in Chapter 11 Project Cost. CAPEX for each project includes transmission pipes and distribution pipes, and disbursed by three and two years for WTPs and transmission/distribution pipes, respectively. Prices are expressed by multiplying the price estimates in 2021 with cumulative inflation at the time of disbursement. OPEX are those assumed in the PPWSA's latest financial plan except that NRW is assumed at 10% according to the management target and the numbers of each WTP are those stipulated in Chapter 9 Human Resources Development.

Table 12.4.1 Assumptions for the Financial Analysis

Water Production and Connections	Unit	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
PPWSA Financial Plan	mn m3/year	245	249	287	293	300	307	315	323	329	336
Additional by JICA Survey	mn m3/year	0	0	0	0	0	15	86	86	188	308
Total	mn m3/year	245	249	287	293	300	322	401	409	517	644
For PPP Case*	mn m3/year	245	249	287	293	300	322	401	409	463	517
Number of connections	1,000	443	470	500	528	628	663	697	737	780	828
CAPEX	Unit	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cost in 2021 price (000,000KHR)											
Phun Prek Phase III	mn KHR/year	0	0	52,585	52,585	91,401	0	0	0	0	0
Bakheng Phase III	mn KHR/year	0	0	0	210,563	272,304	272,304	0	0	0	0
Equipment Update of Chroy Changva	mn KHR/year	0	0	0	0	0	45,471	45,471	0	0	0
Nirodh Phase III	mn KHR/year	0	0	0	0	0	219,530	291,353	291,353	0	0
Koh Norea	mn KHR/year	0	0	0	0	0	150,121	398,193	398,193	0	0
Ta Mouk Phase I	mn KHR/year	0	0	0	0	0	0	296,213	487,236	487,236	0
Khsach Kandal	mn KHR/year	0	0	0	0	0	0	105,436	108,466	108,466	0
New Airport City	mn KHR/year	0	0	0	0	0	0	27,896	37,618	37,618	0
Reconstruction of Phum Prek Phase I	mn KHR/year	0	0	0	0	0	0	0	138,415	138,415	138,415
Ta Mouk Phase II	mn KHR/year	0	0	0	0	0	0	0	147,292	278,755	278,755
Total	mn KHR/year	0	0	52,585	263,148	363,705	687,425	1,164,561	1,608,573	1,050,489	417,170
Cost in time of implementation (000,000KHR)											
Phun Prek Phase III	mn KHR/year	0	0	55,788	57,461	102,873	0	0	0	0	0
Bakheng Phase III	mn KHR/year	0	0	0	230,088	306,480	315,674	0	0	0	0
Equipment Update of Chroy Changva	mn KHR/year	0	0	0	0	0	52,713	54,295	0	0	0
Nirodh Phase III	mn KHR/year	0	0	0	0	0	254,495	347,890	358,327	0	0
Koh Norea	mn KHR/year	0	0	0	0	0	174,032	475,463	489,727	0	0
Ta Mouk Phase I	mn KHR/year	0	0	0	0	0	0	353,693	599,239	617,216	0
Khsach Kandal	mn KHR/year	0	0	0	0	0	0	125,896	133,399	137,401	0
New Airport City	mn KHR/year	0	0	0	0	0	0	33,310	46,266	47,654	0
Reconstruction of Phum Prek Phase I	mn KHR/year	0	0	0	0	0	0	0	170,233	175,340	180,600
Ta Mouk Phase II	mn KHR/year	0	0	0	0	0	0	0	181,151	353,118	363,712
Total	mn KHR/year	0	0	55,788	287,549	409,353	796,914	1,390,547	1,978,341	1,330,729	544,312
OPEX	Unit	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Inflation	%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Electricity price	KHR/kWh	578	578	578	578	578	578	578	578	578	578
NRW rate	%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Salaries per staff	mn KHR/year	44.3	45.1	46.1	47.0	47.9	48.9	49.8	50.8	51.9	52.9
Salaries growth rate	%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Number of staff for production											
Bakheng Phase III	personnel	0	0	0	0	0	0	0	8	8	8
Nirodh Phase III	personnel	0	0	0	0	0	0	0	0	8	8
Koh Norea	personnel	0	0	0	0	0	0	0	0	35	35
Ta Mouk Phase I	personnel	0	0	0	0	0	0	0	0	0	35
Khsach Kandal	personnel	0	0	0	0	0	0	0	0	0	35
Electricity consumption rate											
Bakheng Phase III	Wh/m3	275	275	275	275	275	275	275	275	275	275
Nirodh Phase III	Wh/m3	283	283	283	283	283	283	283	283	283	283
Koh Norea	Wh/m3	279	279	279	279	279	279	279	279	279	279
Ta Mouk Phase I	Wh/m3	288	288	288	288	288	288	288	288	288	288
Khsach Kandal	Wh/m3	292	292	292	292	292	292	292	292	292	292
Raw materials cost	KHR/m3	48	51	52	54	56	57	59	61	63	65
Repairs and maintenance cost	%	0.65%	0.65%	0.65%	0.65%	0.65%	0.65%	0.65%	0.65%	0.65%	0.65%
Distribution cost	KHR/m3	268	284	293	302	311	320	330	339	350	360

*Note: PPP Case assumes bulk water purchase for Koh Norea and Ta Mouk I&II of which water production is subtracted from production amount
Source: JICA Data Collection Survey Team

12.5 FINANCIAL EVALUATION FOR THE PROPOSED PROJECTS

12.5.1 Net Present Cost of Water

In this section, net present cost of water is estimated for the proposed project. Results are shown for the five major projects (Nirodh III, Bakheng III, Koh Norea, Ta Mouk I and, Khsach Kandal).

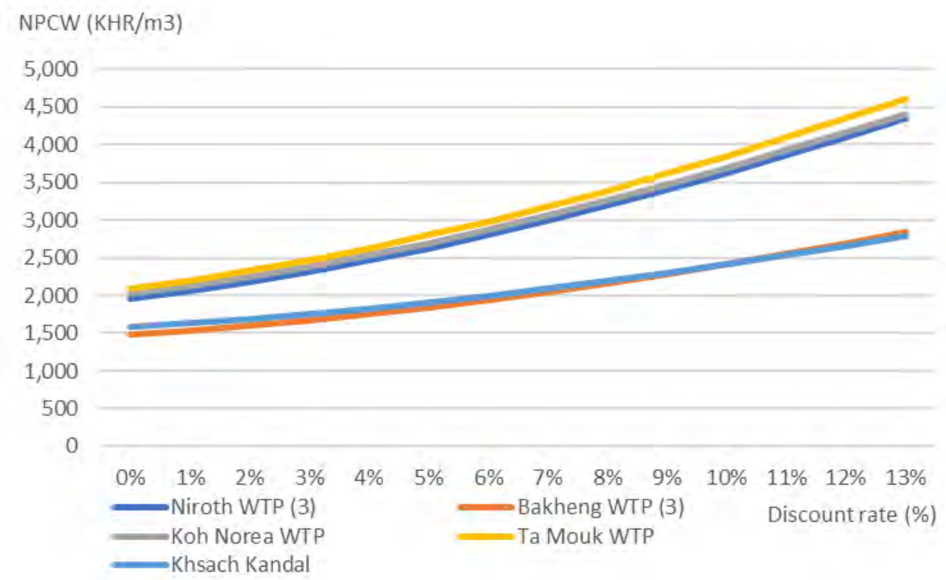


Figure 12.5.1 Net Present Cost of Water for the Proposed Projects

Source: JICA Data Collection Survey Team

The results vary depending on the projects, but NPCW is about KHR2,400/m^3 on capacity-weighted average for the projects combined, assuming 5% discount rate and including distribution cost. In the Master Plan it was estimated about KHR1,600-1,900/m^3 for Bakheng and Chamcar Mon. These are actually in the same cost range considering these projects are 10 years behind Bakheng and Chamcar Mon and cumulative inflation is about 40% assuming 3% inflation rate per year. Bakheng III with existing pipelines and short distance to the intake, and Khsach Kandal utilizing existing distribution pipelines by private companies have the lowest NPCW at around KHR 1,900/m^3. Ta Mouk is the most expensive at KHR2,800/m^3 even though it includes some up-front investment for phase II.

12.5.2 Financial Internal Rate of Return

This section estimates financial internal rate of return for the proposed projects based on the definitions and assumptions above.

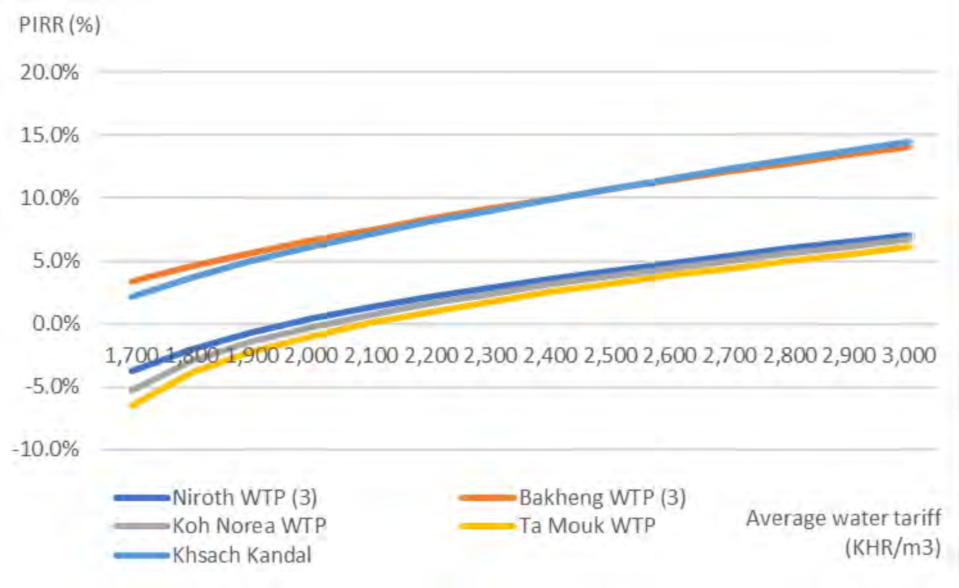


Figure 12.5.2 Financial Internal Rate of Return for the Proposed Projects

Source: JICA Data Collection Survey Team

It is obvious that the water tariff must be increased to the net present cost of water estimated in the previous section (KHR2,400/m³), for the proposed projects to be independently financially feasible. In particular, it needs to be KHR1,900m³ for the PIRR of the most profitable project (Bakheng III and Khsach Kandal) to be 5%. For the least profitable project (Ta Mouk) it needs to be KHR2,800/m³. Noting the Master Plan emphasized that KHR1,700/m³ was really a minimum requirement, this study proposes that ideally, PPWSA should increase the water tariff to KHR2,400/m³ in the mid- term.

12.6 FINANCING OPTIONS

12.6.1 Internal Financing

Internal financing utilizes operating cashflow generated from existing facilities. There is no restriction on the use of the cash/funds, and PPWSA may utilize the cash/funds not only for water treatment facilities/distribution facilities but also for organizational human resources or information systems. It should be noted that the operating cashflow of fiscal year 2020 was approximately KHR billion. This is insufficient compared to the project costs for the Facility Plan in this survey. Therefore, external financing will be necessary. Operating cashflow is also a source of dividend so PPWSA shall obtain consent from the equity holders.

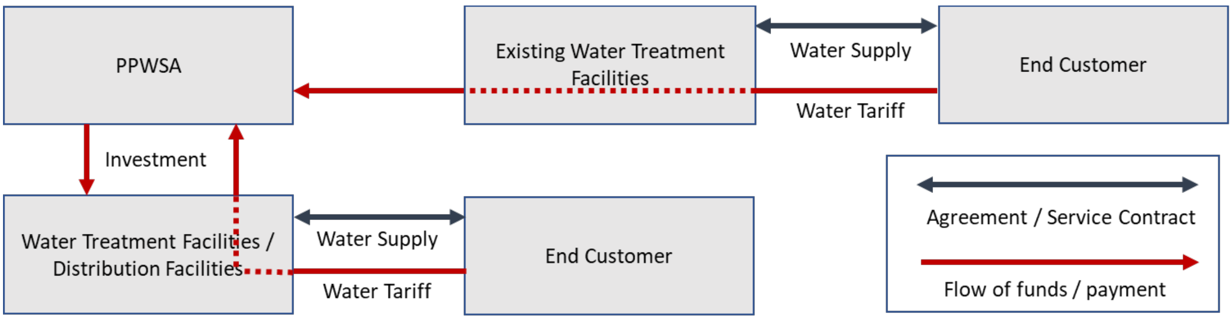


Figure 12.6.1 Internal Financing

Source: JICA Data Collection Survey Team

12.6.2 Government Grants

Government grants come from bilateral or multilateral agreements between governments for a specific project. PPWSA has no obligation to pay back the funds so it is the most favourable to PPWSA's financials among other financing options. However, it may be utilized only for limited projects (e.g., water supply to the poorest), and the size of the funds is generally limited that a single grant may not be sufficient to finance a project proposed in this survey. There may be restrictions on the procurement process as well (e.g., tied to companies based in the doner government).

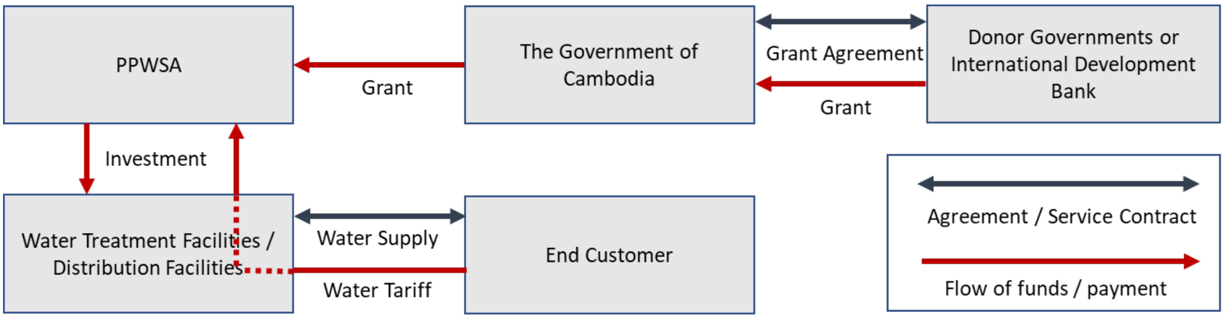


Figure 12.6.2 Government Grants
Source: JICA Data Collection Survey Team

12.6.3 Government Loans

Government loans are a form of debt finance and come from bilateral or multilateral agreements between governments for a specific project. PPWSA has obligation to pay back the funds, but the interest rates are generally low compared to commercial loans. There may be less restrictions on the procurement process as compared to government grants. PPWSA has plenty of experience in government loans. Therefore, it may be the most feasible option for financing. It shall be noted that debt-equity ratio would increase and financial stability must be properly managed.

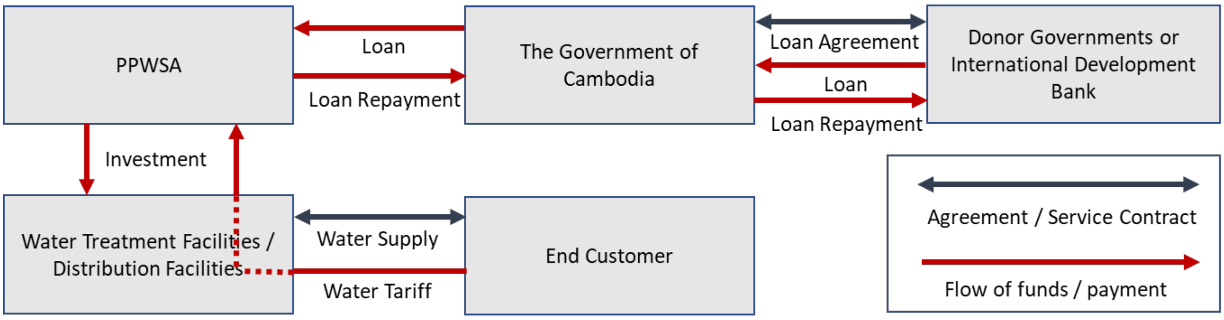


Figure 12.6.3 Government Loans
Source: JICA Data Collection Survey Team

12.6.4 Equity Finance

Equity finance is a major option for financing and PPWSA would have no obligation for repayment. There is no restriction on the use of the cash/funds. PPWSA can utilize the cash/funds not only for water treatment facilities/distribution facilities but also for organizational human resources or information systems. It improves debt-equity ratio and, therefore, has a positive impact on financial stability. There would be a dilution effect to existing equity holders so PPWSA must explain the purpose and merits of the equity injection. It will not impose cost on income statement but generally expected return for equity is higher compared to debt/loan and requires dividend payment in the long-term.

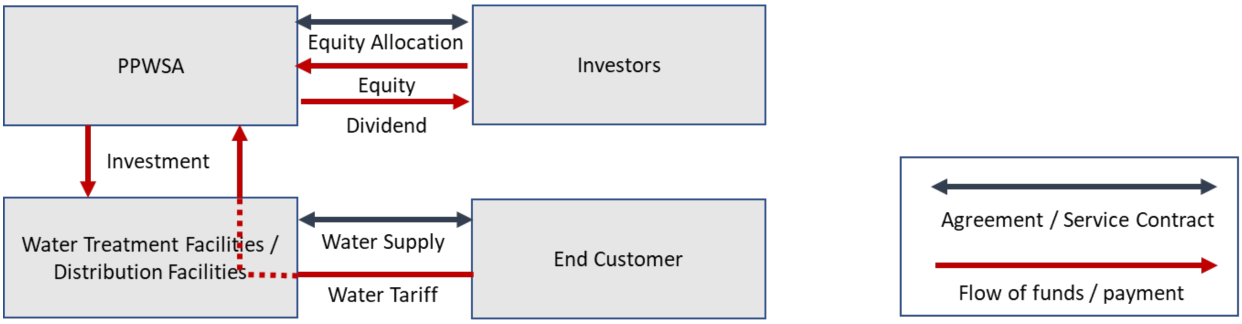


Figure 12.6.4 Equity Finance
Source: JICA Data Collection Survey Team

12.6.5 Corporate Finance

Corporate finance (debt finance, commercial loans) is lending from commercial banks owning to corporate credit. There are less restrictions on the use of the funds compared to government grants or loans and the funds may be utilized for profitable projects or distribution facilities. PPWSA has obligation to pay back the funds, and the interest rates are generally high compared to government loans. As in the case of government loans, debt-equity ratio would increase, and financial stability must be properly managed.

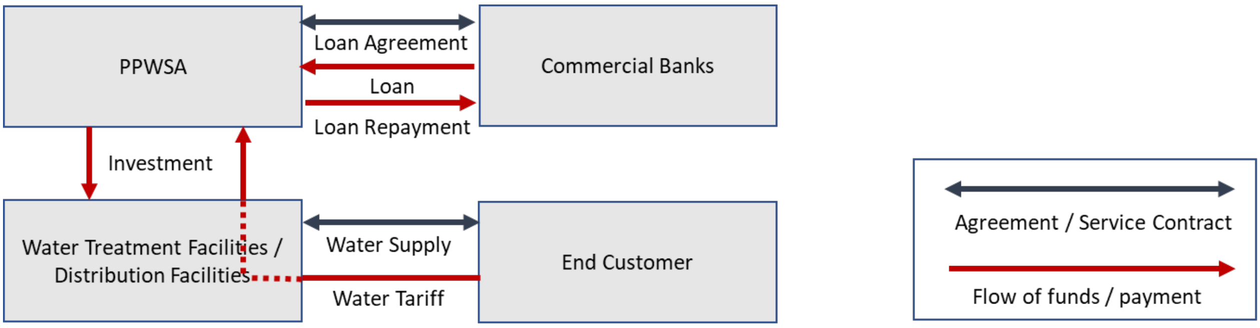


Figure 12.6.5 Corporate Finance

Source: JICA Data Collection Survey Team

12.6.6 Project Finance

Project finance is a financing scheme for a specific project through a special purpose company (SPC), and debt will be repaid by cashflow from the Project. PPWSA pays a concession fee to the SPC, an asset-owning entity, and operates the facilities to produce treated water. It enables PPWSA to operate the facility along with other existing facilities. Generally, the liability is limited to the assets specific to the project and non-recourse to PPWSA. If PPWSA does not inject equity in the SPC the assets and liability of the SPC will not be consolidated in PPWSA's financials. Therefore, the project would be off of the balance sheet and debt-equity ratio would not be affected. It shall be noted, however, that project finance generally requires financial/legal consulting fees. It is applicable to water treatment facilities but not suitable to distribution facilities as the scheme assumes payment based on direct cashflow from the project.

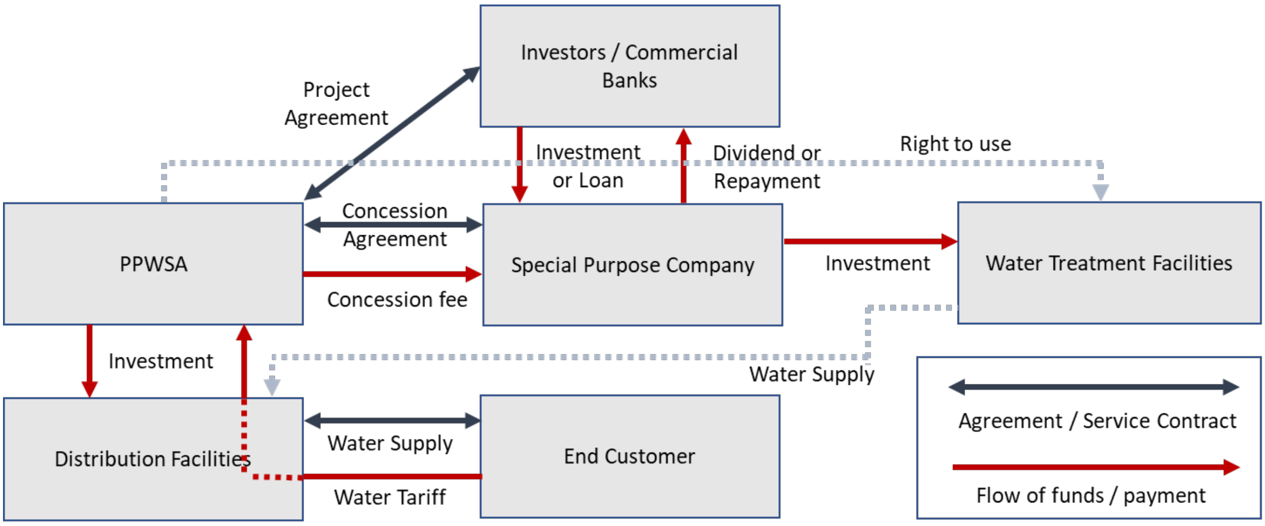


Figure 12.6.6 Project Finance

Source: JICA Data Collection Survey Team

12.6.7 Public-Private Partnership

Public-Private Partnership (PPP) utilizes private finance and know-how to procure public services. A private company design-finance-build-operate the facilities and supply bulk water to PPWSA, and PPWSA in return pays for the service. It enables PPWSA to increase its supply capacity without its own finance or investment. It also benefits PPWSA in a way that operation risks will be borne by the private company, utilizing its know-how and technology, and reducing life-cycle costs. As in the case of project finance, it requires financial/legal consulting fees. The financing cost of a private company is generally higher than that of PPWSA. Therefore, the price of bulk water would likely be high. It is applicable to water treatment facilities but not suitable to distribution facilities as the scheme assumes payment based on bulk water supply.

It should be noted that PPP will likely require increase in water tariff and/or viability gap funding (VGF) from the national government. PPWSA has received unsolicited proposals from private companies in the past but have not reached to agreement on bulk water price. PPWSA's existing operation has been profitable and sustainable under the current water tariff due to cheaper projects and grants received from the development partners in the past. However, future investment will likely require KHR 2,400/m³ to be financially feasible. VGF may be introduced in various forms, and details shall be discussed with the Cambodian government and development partners. As a conclusion, PPP may be introduced only when public funds/grants are insufficient to implement the proposed projects.

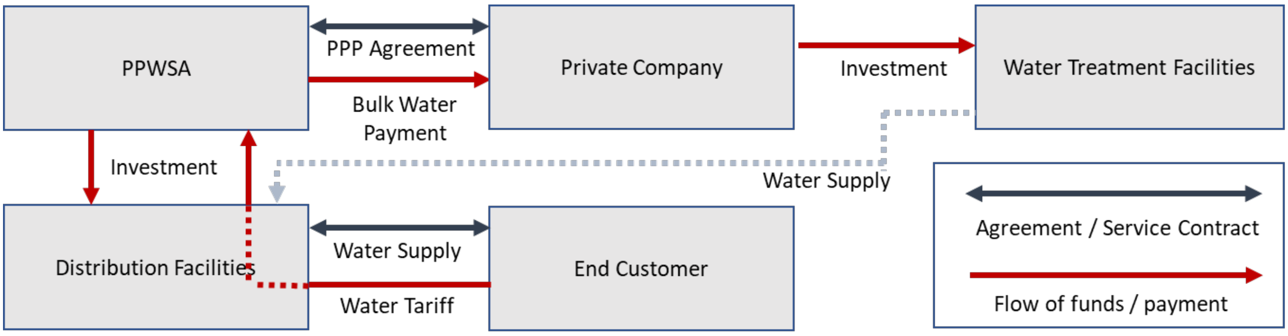


Figure 12.6.7 Public-Private Partnership

Source: JICA Data Collection Survey Team

Overview of Public-Private Partnerships in Cambodia

As pf September 2021, Law on Concession, 2007: Royal Decree No. NS/RKM/1007/027 has been enforced in Cambodia in order to promote and facilitate the implementation of privately financed projects for public interest and the fulfillment of the national economic and social objectives. Concession in the Law means any act attributable to the state whereby a competent institution entrusts to a private third party the total or partial implementation of an Infrastructure Project for which that institution would normally be responsible and for which the third party assumes a major part of the construction and/or operating risks or receives a benefit by way of compensation from government revenue or from fees and charges collected from users or customers. Such acts of the state will be considered as concession under the Law regardless of the legal name used for the act. Article 5 of the Law refers to water supply sector as one of the applicable sectors, and therefore the Law would likely apply to a project in which a private company constructs a water treatment plant and supplies bulk water to PPWSA. However, the Law is a basic law, and detailed rules and procedures are to be specified in the Sub-Decree, which has not been enforced by now, therefore concession projects are being implemented ad hoc basis. As part of institutional arrangement Inter-Ministerial Committee (IMC) was established in 2016 to manage concession projects but is not fully empowered.

The Government of Cambodia also published a Policy Paper on Public-Private Partnerships in 2016 to promote private finance and technologies via PPP given the growing demand in infrastructure and limitation in national budget and international assistance from development partners. The Paper has set out immediate policy measures and medium to long-term policy measures. The immediate policy measures include developing legitimate framework including the Sub-Decree, institutional framework by IMC and human resource development. In the immediate term PPP projects shall be the "Revenue-based Payment" in order to avoid pressure on national budget. In case a PPP project is implemented by PPWSA, it will likely be an "Availability-based Payment" because PPWSA as a public sector pays to a private company for bulk water. But the payment by PPWSA is tied to payment from the end-user therefore it may be deemed Revenue-based Payment in essence. Also noting water supply is one of the priority sectors, PPP project by PPWSA is in accordance with the national policy.

As a conclusion PPP may be a feasible option for PPWSA to finance new projects, and the relevant parties shall confirm the latest laws and regulations noting that PPP scheme is under development in Cambodia.

12.6.8 Recommendation

Summary of the financing options is illustrated below.

	Funds Size	Impact on profitability	Impact on financial soundness	Target Project	Restrictions on procurement
Internal Financing	Small	Positive (Large)	None	No restriction	No
Government Grants	Middle	Positive (Large)	None	WTPs/transmission pipelines	Yes
Government Loans	Large	Positive (Small)	Negative	WTPs/transmission pipelines	Yes
Equity Finance	Large	Positive (Large)	Positive	No restriction	No
Corporate Finance (Commercial Loans)	Large	Negative (Small)	Negative	No restriction	No
Project Finance	Large	Negative (Large)	None	WTPs only	No
PPP	Large	Negative (Large)	None	WTPs only	No

Figure 12.6.8 Comparison of Financing Options

Source: JICA Data Collection Survey Team

12.7 IMPACT OF THE PROPOSED PROJECT ON PPWSA'S FINANCE

12.7.1 Base Case Analysis

In this section, the impact of the proposed projects on PPWSA's finances are studied using a financial model. The assumptions other than those for the proposed projects shall be the same as PPWSA's latest financial forecast. The assumptions for the base case analysis are illustrated below. It should be noted that especially inflation rate has high uncertainty due to COVID-19 and the actual cost may vary in the implementation phase.

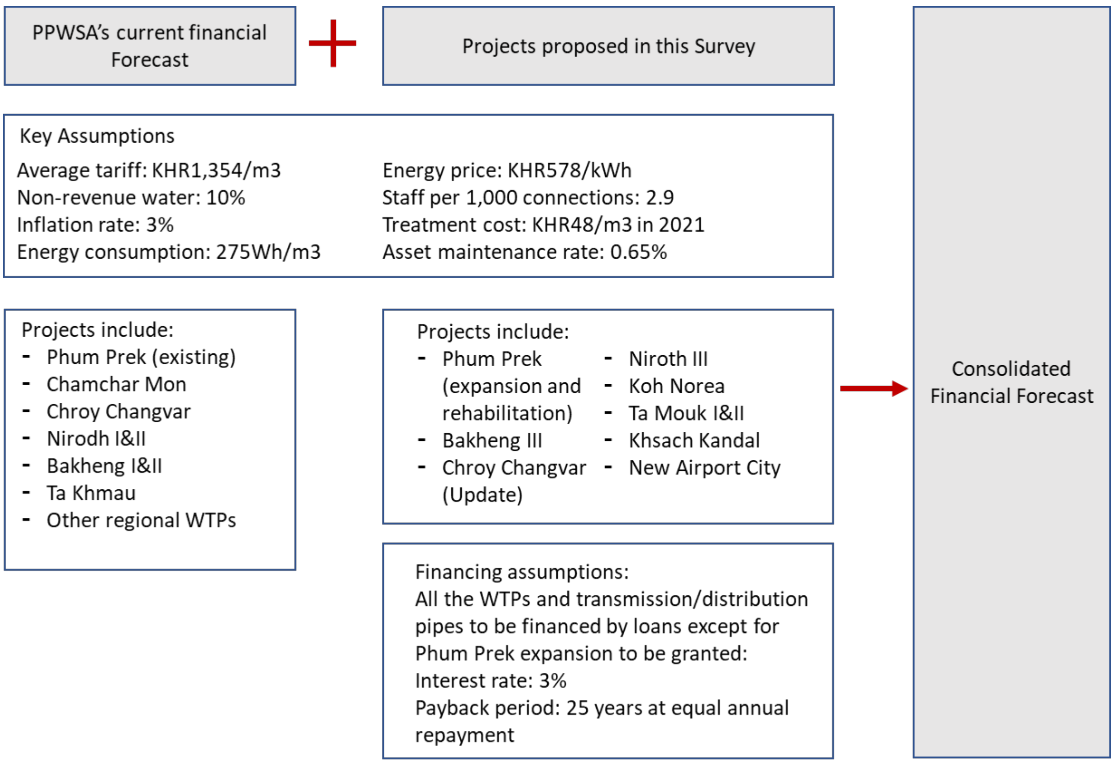


Figure 12.7.1 Assumptions for the Base Case

Source: JICA Data Collection Survey Team

The summary of the results of financial modelling based on the assumptions above is illustrated below.

Also shown is the difference between the results and PPWSA's latest financial forecast.

Table 12.7.1 Financial Forecast (Base Case)

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	224,774	245,000	249,000	287,000	293,000	300,000	321,714	401,087	408,660	517,376	644,400
Water Tariff	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354
Total Income	324,368	357,602	360,340	417,765	440,688	496,411	484,929	592,369	607,080	756,946	933,656
Operating Profit	129,587	138,843	133,138	170,549	128,271	127,913	88,194	109,701	27,192	22,736	79,649
Operating Margin	40.0%	38.8%	36.9%	40.8%	29.1%	25.8%	18.2%	18.5%	4.5%	3.0%	8.5%
Net Profit	88,352	107,065	103,604	134,478	94,371	89,822	67,828	91,268	30,154	-4,301	-11,248
Net Margin	27.2%	29.9%	28.8%	32.2%	21.4%	18.1%	14.0%	15.4%	5.0%	-0.6%	-1.2%
Cash&ST Inv	118,155	116,707	89,042	334,975	415,685	960,047	1,603,858	2,233,966	1,427,618	304,573	-528,132
Total Indebtedness	548,136	846,918	1,143,914	1,609,454	1,889,948	2,644,001	4,024,275	5,957,521	7,184,064	7,561,692	7,284,871
Equity	982,053	1,106,120	1,209,725	1,344,203	1,438,573	1,528,396	1,596,223	1,687,491	1,717,645	1,713,344	1,702,095
DSCR	1.6	4.3	5.4	6.6	4.1	3.8	3.1	2.2	1.6	1.4	1.3
Net debt to EBITDA	2.3	3.7	5.5	5.6	6.2	6.4	10.1	12.2	19.4	18.3	15.1
Debt on Equity	55.8%	76.6%	94.6%	119.7%	131.4%	173.0%	252.1%	353.0%	418.3%	441.3%	428.0%
(KHR '000 000)		2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production		723,973	730,546	737,119	739,855	739,855	739,855	739,855	739,855	739,855	739,855
Water Tariff		1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354
Total Income		1,042,470	1,052,610	1,062,814	1,067,891	1,027,879	1,027,667	1,027,476	1,027,304	1,027,150	1,027,011
Operating Profit		142,347	157,069	170,039	177,754	159,146	170,552	180,889	190,224	198,606	206,064
Operating Margin		13.7%	14.9%	16.0%	16.6%	15.5%	16.6%	17.6%	18.5%	19.3%	20.1%
Net Profit		-63,353	-47,620	-29,741	-16,388	-24,285	-9,046	5,833	19,981	33,260	45,803
Net Margin		-6.1%	-4.5%	-2.8%	-1.5%	-2.4%	-0.9%	0.6%	1.9%	3.2%	4.5%
Cash&ST Inv		-666,285	-676,669	-683,159	-687,684	-722,501	-722,604	-703,432	-677,594	-632,469	-573,613
Total Indebtedness		6,951,056	6,589,195	6,234,589	5,889,570	5,554,855	5,230,151	4,927,469	4,635,254	4,367,694	4,119,279
Equity		1,638,743	1,591,123	1,561,382	1,544,994	1,520,709	1,511,663	1,517,496	1,536,310	1,565,574	1,604,725
DSCR		1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.2	1.3
Net debt to EBITDA		12.8	12.3	11.8	11.4	11.7	11.2	10.7	10.2	9.7	9.2
Debt on Equity		424.2%	414.1%	399.3%	381.2%	365.3%	346.0%	324.7%	301.7%	279.0%	256.7%

Difference

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	0	0	0	0	0	0	14,600	85,775	85,775	187,975	308,425
Water Tariff	0	0	0	0	0	0	0	0	0	0	0
Total Income	0	14,708	11,503	14,974	14,979	61,685	42,420	141,981	147,528	289,297	457,673
Operating Profit	0	10,591	6,952	8,146	4,913	25,522	-17,014	1,146	-85,753	-93,702	-40,801
Operating Margin	0.0%	1.4%	0.8%	0.5%	0.1%	2.2%	-5.6%	-5.6%	-20.1%	-21.9%	-16.8%
Net Profit	0	8,473	5,921	6,940	8,348	26,621	1,059	19,046	-48,450	-88,281	-98,994
Net Margin	0.0%	1.2%	0.7%	0.5%	1.2%	3.6%	-1.1%	-0.6%	-12.1%	-18.5%	-19.6%
Cash&ST Inv	0	15,815	18,582	256,491	355,212	865,004	1,411,854	1,967,462	1,111,892	-63,812	-961,995
Total Indebtedness	0	0	0	230,088	538,696	1,338,445	2,727,160	4,696,816	5,992,307	6,439,841	6,257,004
Equity	0	8,473	14,393	21,333	29,681	56,302	57,361	76,407	27,958	-60,323	-159,317
DSCR	0.0	0.3	0.3	0.4	0.0	0.6	-0.7	-0.4	-0.4	-0.6	-0.7
Net debt to EBITDA	0.0	-0.3	-0.3	-0.3	0.6	1.3	5.4	8.0	15.7	15.2	12.6
Debt on Equity	0.0%	-0.6%	-1.1%	15.5%	35.5%	84.3%	167.8%	274.8%	347.7%	378.1%	372.8%
(KHR '000 000)		2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production		381,425	381,425	381,425	381,425	381,425	381,425	381,425	381,425	381,425	381,425
Water Tariff		0	0	0	0	0	0	0	0	0	0
Total Income		557,812	559,232	560,678	562,035	531,081	531,081	531,081	531,081	531,081	531,081
Operating Profit		16,206	25,618	33,611	40,382	28,698	40,373	51,223	61,310	70,669	79,333
Operating Margin		-12.4%	-11.7%	-11.2%	-10.5%	-10.8%	-9.6%	-8.5%	-7.5%	-6.5%	-5.5%
Net Profit		-158,625	-150,355	-139,232	-129,396	-134,461	-121,485	-108,740	-96,627	-85,142	-74,298
Net Margin		-25.7%	-25.3%	-24.6%	-23.9%	-24.5%	-23.5%	-22.5%	-21.6%	-20.6%	-19.8%
Cash&ST Inv		-1,177,610	-1,239,487	-1,299,032	-1,354,017	-1,428,672	-1,474,192	-1,511,168	-1,541,015	-1,565,779	-1,585,724
Total Indebtedness		6,017,311	5,759,718	5,509,438	5,268,745	5,038,356	4,817,979	4,607,229	4,405,695	4,212,976	4,028,687
Equity		541,095	395,792	238,512	136,101	48,615	-27,199	-93,588	-153,378	-208,093	-256,688
DSCR		-1.0	-0.9	-0.9	-0.9	-0.9	-0.9	-1.1	-1.1	-1.5	-1.9
Net debt to EBITDA		11.1	11.2	11.4	11.6	12.5	12.6	12.8	13.0	13.3	13.5
Debt on Equity		376.4%	373.5%	365.2%	353.2%	342.9%	328.8%	311.9%	292.8%	273.2%	253.4%

Source: JICA Data Collection Survey Team

This survey proposes an ambitious investment plan to increase the production capacity by 1,045,000m³/day which will have a significant impact on PPWSA finances. Total income would increase by 96% to KHR934bn in 2030. However, operating margin and net margin would decrease by 16.8 percentage points to 8.5% and 19.6 percentage points to -1.2% respectively, given that the water tariff is assumed to be much lower than the production cost of water by the proposed projects. The facility plan also requires investment and financing in large scale. Therefore, financial stability must also be considered. Cash and short-term investment will be negative from 2030 which simply indicates the investments are not financially feasible. Having noted above, next section will analyse a case in which the water tariff will increase to secure the profitability and financial stability.

12.7.2 Optimal Case Analysis

Given the Base Case analysis, this Optimal Case will assume a gradual increase of water tariff to KHR2,400/m³ by 2030. The summary of the results and comparison to the Base Case are illustrated below.

Table 12.7.2 Financial Forecast (Optimal Case)

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	224,774	245,000	249,000	287,000	293,000	300,000	321,714	401,087	408,660	517,376	644,400
Water Tariff	1,354	1,354	1,354	1,354	1,354	1,400	1,600	1,800	2,000	2,200	2,400
Total Income	324,368	357,602	360,340	417,765	440,688	510,700	566,682	775,953	877,877	1,203,463	1,618,466
Operating Profit	129,587	138,843	133,138	170,549	128,271	141,018	163,141	277,892	275,078	431,396	706,196
Operating Margin	40.0%	38.8%	36.9%	40.8%	29.1%	27.6%	28.8%	35.8%	31.3%	35.8%	43.6%
Net Profit	88,352	107,065	103,604	134,478	94,371	100,306	128,219	228,559	235,777	335,955	513,679
Net Margin	27.2%	29.9%	28.8%	32.2%	21.4%	19.6%	22.6%	29.5%	26.9%	27.9%	31.7%
Cash&ST Inv	118,155	116,707	89,042	334,975	415,685	978,232	1,718,669	2,540,303	1,985,298	1,295,525	1,113,267
Total Indebtedness	548,136	846,918	1,143,914	1,609,454	1,889,948	2,644,001	4,024,275	5,957,521	7,184,064	7,561,692	7,284,871
Equity	982,053	1,106,120	1,209,725	1,344,203	1,438,573	1,538,879	1,667,098	1,895,658	2,131,435	2,467,389	2,981,068
DSCR	1.6	4.3	5.4	6.6	4.1	3.9	3.8	3.3	2.6	2.6	2.6
Net debt to EBITDA	2.3	3.7	5.5	5.6	6.2	6.0	7.3	7.2	9.5	7.8	5.4
Debt on Equity	55.8%	76.6%	94.6%	119.7%	131.4%	171.8%	241.4%	314.3%	337.1%	306.5%	244.4%

(KHR '000 000)		2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production		723,973	730,546	737,119	739,855	739,855	739,855	739,855	739,855	739,855	739,855
Water Tariff		2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total Income		1,810,431	1,827,439	1,844,512	1,852,447	1,812,436	1,812,224	1,812,033	1,811,861	1,811,706	1,811,567
Operating Profit		844,177	864,238	882,577	892,127	872,725	883,329	892,847	901,353	908,893	915,494
Operating Margin		46.6%	47.3%	47.8%	48.2%	48.2%	48.7%	49.3%	49.7%	50.2%	50.5%
Net Profit		537,362	572,737	609,784	637,193	641,371	668,800	696,127	722,880	748,954	774,523
Net Margin		29.7%	31.3%	33.1%	34.4%	35.4%	36.9%	38.4%	39.9%	41.3%	42.8%
Cash&ST Inv		1,616,288	2,225,663	2,743,693	3,268,812	3,768,657	4,314,537	4,886,579	5,473,546	6,090,019	6,730,621
Total Indebtedness		6,951,056	6,589,195	6,234,589	5,889,570	5,554,855	5,230,151	4,927,469	4,635,254	4,367,694	4,119,279
Equity		3,518,431	4,091,168	4,586,405	5,101,641	5,615,573	6,156,098	6,718,466	7,302,121	7,906,498	8,531,231
DSCR		2.2	2.2	2.3	2.4	2.4	2.5	2.7	2.8	3.0	3.2
Net debt to EBITDA		4.1	3.4	2.7	2.0	1.4	0.7	0.0	-0.7	-1.4	-2.1
Debt on Equity		197.6%	161.1%	135.9%	115.4%	98.9%	85.0%	73.3%	63.5%	55.2%	48.3%

Difference

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	0	0	0	0	0	0	0	0	0	0	0
Water Tariff	0	0	0	0	0	46	246	446	646	846	1,046
Total Income	0	0	0	0	0	14,289	81,753	183,585	270,797	446,517	684,810
Operating Profit	0	0	0	0	0	13,105	74,948	168,191	247,886	408,660	626,547
Operating Margin	0.0%	0.0%	0.0%	0.0%	0.0%	1.8%	10.6%	17.3%	26.9%	32.8%	35.1%
Net Profit	0	0	0	0	0	10,484	60,392	137,291	205,623	340,256	524,927
Net Margin	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	8.6%	14.0%	21.9%	28.5%	32.9%
Cash&ST Inv	0	0	0	0	0	18,184	114,812	306,337	557,680	990,951	1,641,400
Total Indebtedness	0	0	0	0	0	0	0	0	0	0	0
Equity	0	0	0	0	0	10,484	70,875	208,167	413,790	754,046	1,278,973
DSCR	0.0	0.0	0.0	0.0	0.0	0.1	0.8	1.1	1.0	1.2	1.3
Net debt to EBITDA	0.0	0.0	0.0	0.0	0.0	-0.4	-2.8	-5.0	-9.8	-10.5	-9.7
Debt on Equity	0.0%	0.0%	0.0%	0.0%	0.0%	-1.2%	-10.7%	-38.8%	-81.2%	-134.9%	-183.6%

(KHR '000 000)	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production	0	0	0	0	0	0	0	0	0	0
Water Tariff	1,046	1,046	1,046	1,046	1,046	1,046	1,046	1,046	1,046	1,046
Total Income	767,961	774,829	781,698	784,557	784,557	784,557	784,557	784,557	784,557	784,557
Operating Profit	701,830	707,168	712,538	714,373	713,579	712,777	711,958	711,128	710,287	709,430
Operating Margin	33.0%	32.4%	31.8%	31.5%	32.7%	32.1%	31.7%	31.2%	30.8%	30.5%
Net Profit	600,715	620,357	639,525	653,580	665,656	677,846	690,294	702,900	715,694	728,720
Net Margin	35.8%	35.9%	35.9%	35.9%	37.7%	37.8%	37.8%	38.0%	38.1%	38.3%
Cash&ST Inv	2,282,573	2,902,333	3,426,852	3,956,496	4,491,158	5,037,141	5,590,011	6,151,140	6,722,488	7,304,234
Total Indebtedness	0	0	0	0	0	0	0	0	0	0
Equity	1,879,688	2,500,045	3,025,023	3,556,647	4,094,864	4,644,436	5,200,970	5,765,811	6,340,925	6,926,506
DSCR	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.8	2.0
Net debt to EBITDA	-8.7	-8.9	-9.1	-9.4	-10.2	-10.4	-10.7	-10.9	-11.1	-11.4
Debt on Equity	-226.6%	-253.1%	-263.4%	-265.8%	-266.4%	-261.0%	-251.4%	-238.2%	-223.7%	-208.4%

Source: JICA Data Collection Survey Team

Operating margin and net margin in 2030 would increase significantly by 35.1 percentage points to 43.6% and by 32.9 percentage points to 31.7%, respectively. Net debt to EBITDA would decrease to 5.4 improving payback capacity, but debt to equity is still high at 244%. The next section will analyse a case in which some of the proposed projects are implemented by PPP to reduce net debt and gain financial leverage.

12.7.3 PPP Case Analysis

Given the Optimal Case analysis, this PPP Case assumes that Koh Norea and Ta Mouk are implemented by PPP. Price of bulk water to be paid by PPWSA is assumed to be the estimated production cost of the proposed projects plus the operator's profit at 35%. The summary of the results and comparison to the Optimal Case are illustrated below.

Table 12.7.3 Financial Forecast (PPP Case)

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	224,774	245,000	249,000	287,000	293,000	300,000	321,714	401,087	408,660	462,626	516,650
Water Tariff	1,354	1,354	1,354	1,354	1,354	1,400	1,600	1,800	2,000	2,200	2,400
Total Income	324,368	357,602	360,340	417,765	440,688	510,700	566,682	775,953	877,877	1,203,463	1,618,466
Operating Profit	129,587	138,843	133,138	170,549	128,271	141,018	164,707	295,515	345,074	396,323	475,590
Operating Margin	40.0%	38.8%	36.9%	40.8%	29.1%	27.6%	29.1%	38.1%	39.3%	32.9%	29.4%
Net Profit	88,352	107,065	103,604	134,478	94,371	100,306	126,583	228,583	269,821	297,404	348,618
Net Margin	27.2%	29.9%	28.8%	32.2%	21.4%	19.6%	22.3%	29.5%	30.7%	24.7%	21.5%
Cash&ST Inv	118,155	116,707	89,042	334,975	415,685	804,200	876,265	1,232,291	1,080,078	1,089,669	1,222,654
Total Indebtedness	548,136	846,918	1,143,914	1,609,454	1,889,948	2,469,969	3,019,476	3,674,936	3,926,358	3,971,491	3,782,609
Equity	982,053	1,106,120	1,209,725	1,344,203	1,438,573	1,538,879	1,665,462	1,894,045	2,163,866	2,461,270	2,809,888
DSCR	1.6	4.3	5.4	6.6	4.1	3.9	3.9	3.5	2.8	2.8	2.7
Net debt to EBITDA	2.3	3.7	5.5	5.6	6.2	6.0	6.8	5.1	5.1	4.5	3.5
Debt on Equity	55.8%	76.6%	94.6%	119.7%	131.4%	160.5%	181.3%	194.0%	181.5%	161.4%	134.6%

(KHR '000 000)	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production	523,223	529,796	536,369	539,105	539,105	539,105	539,105	539,105	539,105	539,105
Water Tariff	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total Income	1,810,431	1,827,439	1,844,512	1,852,447	1,812,436	1,812,224	1,812,033	1,811,861	1,811,706	1,811,567
Operating Profit	377,471	388,803	398,889	400,596	373,831	377,531	380,583	383,041	384,933	386,267
Operating Margin	20.8%	21.3%	21.6%	21.6%	20.6%	20.8%	21.0%	21.1%	21.2%	21.3%
Net Profit	246,709	262,326	280,747	291,248	278,811	289,890	301,103	311,958	322,328	332,370
Net Margin	13.6%	14.4%	15.2%	15.7%	15.4%	16.0%	16.6%	17.2%	17.8%	18.3%
Cash&ST Inv	1,399,154	1,654,090	1,866,844	2,077,212	2,252,135	2,462,850	2,689,467	2,920,758	3,171,309	3,435,748
Total Indebtedness	3,579,102	3,360,849	3,146,334	2,936,193	2,730,613	2,529,438	2,344,892	2,165,647	2,006,114	1,861,003
Equity	3,056,597	3,318,923	3,547,204	3,782,303	4,002,865	4,236,992	4,480,117	4,731,854	4,991,791	5,259,695
DSCR	2.2	2.0	2.1	2.1	2.0	2.1	2.3	2.4	2.6	2.8
Net debt to EBITDA	3.4	2.7	2.0	1.4	0.8	0.1	-0.6	-1.3	-2.0	-2.8
Debt on Equity	117.1%	101.3%	88.7%	77.6%	68.2%	59.7%	52.3%	45.8%	40.2%	35.4%

Difference

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	0	0	0	0	0	0	0	0	0	-54,750	-127,750
Water Tariff	0	0	0	0	0	0	0	0	0	0	0
Total Income	0	0	0	0	0	0	0	0	0	0	0
Operating Profit	0	0	0	0	0	0	1,566	17,622	69,996	-35,073	-230,606
Operating Margin	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	2.3%	8.0%	-2.9%	-14.2%
Net Profit	0	0	0	0	0	0	-1,636	23	34,045	-38,551	-165,061
Net Margin	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%	0.0%	3.9%	-3.2%	-10.2%
Cash&ST Inv	0	0	0	0	0	-174,032	-842,404	-1,308,012	-905,220	-205,856	109,387
Total Indebtedness	0	0	0	0	0	-174,032	-1,004,798	-2,282,584	-3,257,705	-3,590,201	-3,502,262
Equity	0	0	0	0	0	0	-1,636	-1,613	32,432	-6,119	-171,181
DSCR	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.1
Net debt to EBITDA	0.0	0.0	0.0	0.0	0.0	0.0	-0.5	-2.1	-4.4	-3.3	-1.9
Debt on Equity	0.0%	0.0%	0.0%	0.0%	0.0%	-11.3%	-60.1%	-120.2%	-155.6%	-145.1%	-109.8%

(KHR '000 000)	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production	-200,750	-200,750	-200,750	-200,750	-200,750	-200,750	-200,750	-200,750	-200,750	-200,750
Water Tariff	0	0	0	0	0	0	0	0	0	0
Total Income	0	0	0	0	0	0	0	0	0	0
Operating Profit	-466,706	-475,435	-483,688	-491,531	-498,893	-505,798	-512,264	-518,312	-523,961	-529,227
Operating Margin	-25.8%	-26.0%	-26.2%	-26.5%	-27.5%	-27.9%	-28.3%	-28.6%	-28.9%	-29.2%
Net Profit	-290,653	-310,411	-329,037	-345,945	-362,559	-378,910	-395,024	-410,923	-426,626	-442,153
Net Margin	-16.1%	-17.0%	-17.8%	-18.7%	-20.0%	-20.9%	-21.8%	-22.7%	-23.5%	-24.4%
Cash&ST Inv	-217,135	-571,574	-876,849	-1,191,600	-1,516,522	-1,851,686	-2,197,112	-2,552,789	-2,918,710	-3,294,873
Total Indebtedness	-3,371,953	-3,228,345	-3,088,255	-2,953,377	-2,824,243	-2,700,713	-2,582,578	-2,469,608	-2,361,579	-2,258,276
Equity	-461,834	-772,245	-1,039,200	-1,319,338	-1,612,708	-1,919,106	-2,238,348	-2,570,266	-2,914,708	-3,271,536
DSCR	0.0	-0.2	-0.2	-0.2	-0.3	-0.4	-0.4	-0.4	-0.4	-0.4
Net debt to EBITDA	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
Debt on Equity	-80.5%	-59.8%	-47.2%	-37.8%	-30.7%	-25.3%	-21.0%	-17.7%	-15.1%	-12.9%

Source: JICA Data Collection Survey Team

Operating margin and net margin will decrease by 14.2 percentage points to 29.4% and 10.2 percentage points to 21.5%, respectively, still maintaining reasonable profitability. Net debt to EBITDA and debt to equity ratio would decrease to 2.7 and 135%, respectively, resulting in better payback capacity and financial position.

12.7.4 Best-effort Case Analysis

While the Optimal Case is ideal for PPWSA's financials, it may not be realistic for PPWSA to increase the water tariff to KHR2,400/m³ in the mid-term. This Best-effort Case analyses the most realistic target for PPWSA. The water tariff is assumed to be increased gradually to KHR1,700/m³ as proposed by the previous Master Plan. Interest rate is deceased from 3% to 1% and no PPP is utilized to improve the profitability on net profit basis. The summary of the results is illustrated below.

Table 12.7.4 Financial Forecast (Best-effort Case)

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	224,774	245,000	249,000	287,000	293,000	300,000	321,714	401,087	408,660	517,376	644,400
Water Tariff	1,354	1,354	1,354	1,400	1,500	1,600	1,700	1,700	1,700	1,700	1,700
Total Income	324,368	357,602	360,340	430,954	485,020	572,828	599,915	734,791	752,120	939,564	1,160,180
Operating Profit	129,587	138,843	133,138	182,644	168,888	198,193	195,633	245,773	171,858	209,763	313,270
Operating Margin	40.0%	38.8%	36.9%	42.4%	34.8%	34.6%	32.6%	33.4%	22.8%	22.3%	27.0%
Net Profit	88,352	107,065	103,604	144,154	128,400	149,365	161,811	218,464	177,196	192,319	248,329
Net Margin	27.2%	29.9%	28.8%	33.5%	26.5%	26.1%	27.0%	29.7%	23.6%	20.5%	21.4%
Cash&ST Inv	118,155	116,707	89,042	351,759	491,349	1,131,509	1,937,591	2,799,941	2,291,064	1,556,504	1,150,516
Total Indebtedness	548,136	846,918	1,143,914	1,609,454	1,888,529	2,640,692	4,016,051	5,940,779	7,155,255	7,525,006	7,245,498
Equity	982,053	1,106,120	1,209,725	1,353,879	1,482,279	1,631,644	1,793,454	2,011,918	2,189,114	2,381,433	2,629,761
DSCR	1.6	4.3	5.4	6.9	4.8	4.7	4.5	3.5	2.4	2.2	2.0
Net debt to EBITDA	2.3	3.7	5.5	5.2	5.0	4.5	6.0	7.2	11.3	10.6	8.4
Debt on Equity	55.8%	76.6%	94.6%	118.9%	127.4%	161.8%	223.9%	295.3%	326.9%	316.0%	275.5%
(KHR '000 000)		2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production		723,973	730,546	737,119	739,855	739,855	739,855	739,855	739,855	739,855	739,855
Water Tariff		1,700	1,700	1,700	1,700	1,700	1,700	1,700	1,700	1,700	1,700
Total Income		1,296,500	1,308,911	1,321,387	1,327,409	1,287,398	1,287,186	1,286,995	1,286,823	1,286,668	1,286,529
Operating Profit		399,222	414,086	427,384	434,355	414,201	424,122	433,024	440,977	448,027	454,196
Operating Margin		30.8%	31.6%	32.3%	32.7%	32.2%	32.9%	33.6%	34.3%	34.8%	35.3%
Net Profit		280,657	301,591	323,136	338,229	331,559	348,222	364,821	380,874	396,266	411,164
Net Margin		21.6%	23.0%	24.5%	25.5%	25.8%	27.1%	28.3%	29.6%	30.8%	32.0%
Cash&ST Inv		1,393,753	1,699,100	1,953,677	2,208,890	2,432,961	2,695,882	2,977,740	3,267,254	3,578,956	3,907,418
Total Indebtedness		6,912,835	6,552,442	6,199,410	5,855,921	5,522,676	5,199,378	4,898,043	4,607,115	4,340,785	4,093,548
Equity		2,910,419	3,212,009	3,474,827	3,748,429	4,012,342	4,294,252	4,589,428	4,897,338	5,217,429	5,549,340
DSCR		1.9	1.8	1.9	1.9	1.9	2.0	2.1	2.2	2.4	2.5
Net debt to EBITDA		6.7	5.9	5.2	4.5	4.0	3.3	2.5	1.8	1.0	0.3
Debt on Equity		237.5%	204.0%	178.4%	156.2%	137.6%	121.1%	106.7%	94.1%	83.2%	73.8%

Source: JICA Data Collection Survey Team

In this case, net debt to EBITDA and debt on equity are high at 8.4 and 276%, respectively, posing a concern in payback capacity and financial position. However, PPWSA will remain reasonably profitable, and cash and short-term investments remain positive. If financial institutions and/or development partners accept the financial instability, the proposed projects may be feasible.

12.7.5 Recommended Case Analysis

In addition to the Best-effort Case, this Recommended Case examines the most realistic water tariff scenario, in which PPWSA will consider the recalculation of water tariff, then average tariff should be reached to KHR1,700/m³ in 2025, then PPWSA will increase the water tariff to KHR1,900/m³ in 2028. The summary of the results is illustrated below.

Table 12.7.5 Financial Forecast (Recommended Case)

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	224,774	245,000	249,000	287,000	293,000	300,000	321,714	401,087	408,660	517,376	644,400
Water Tariff	1,354	1,354	1,354	1,354	1,354	1,700	1,700	1,700	1,900	1,900	1,900
Total Income	324,368	357,602	360,340	417,765	440,688	603,892	599,915	734,791	835,958	1,045,123	1,291,119
Operating Profit	129,587	138,843	133,138	170,549	128,296	226,516	193,583	239,431	229,120	270,215	381,264
Operating Margin	40.0%	38.8%	36.9%	40.8%	29.1%	37.5%	32.3%	32.6%	27.4%	25.9%	29.5%
Net Profit	88,352	107,065	103,604	134,478	94,335	168,687	155,291	202,474	202,734	210,633	247,105
Net Margin	27.2%	29.9%	28.8%	32.2%	21.4%	27.9%	25.9%	27.6%	24.3%	20.2%	19.1%
Cash&ST Inv	118,155	116,707	89,042	331,582	414,746	1,090,140	1,946,190	2,734,067	2,183,305	1,123,844	526,367
Total Indebtedness	548,136	846,918	1,143,914	1,606,061	1,885,844	2,632,826	4,127,768	6,200,110	7,614,043	8,009,899	7,723,565
Equity	982,053	1,106,120	1,209,725	1,344,203	1,438,538	1,607,225	1,762,516	1,964,990	2,167,724	2,378,356	2,625,461
DSCR	1.6	4.3	5.4	6.6	4.1	4.8	4.2	3.1	2.4	2.2	2.0
Net debt to EBITDA	2.3	3.7	5.5	5.6	6.2	4.3	6.3	8.0	10.8	10.5	8.5
Debt on Equity	55.8%	76.6%	94.6%	119.5%	131.1%	163.8%	234.2%	315.5%	351.2%	336.8%	294.2%
(KHR '000 000)		2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production		723,973	730,546	737,119	739,855	739,855	739,855	739,855	739,855	739,855	739,855
Water Tariff		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
Total Income		1,443,337	1,457,062	1,470,851	1,477,420	1,437,409	1,437,197	1,437,006	1,436,834	1,436,679	1,436,540
Operating Profit		483,691	502,482	519,461	529,266	511,322	523,335	534,219	544,049	552,874	560,723
Operating Margin		33.5%	34.5%	35.3%	35.8%	35.6%	36.4%	37.2%	37.9%	38.5%	39.0%
Net Profit		224,579	251,370	280,211	302,011	301,434	323,973	346,257	367,813	388,536	408,602
Net Margin		15.6%	17.3%	19.1%	20.4%	21.0%	22.5%	24.1%	25.6%	27.0%	28.4%
Cash&ST Inv		694,260	989,025	1,247,537	1,509,376	1,742,696	2,017,801	2,314,721	2,622,117	2,954,467	3,306,291
Total Indebtedness		7,372,551	6,992,762	6,620,608	6,258,730	5,907,872	5,567,727	5,250,279	4,943,944	4,662,880	4,401,553
Equity		2,850,040	3,101,410	3,331,347	3,577,316	3,818,348	4,082,034	4,363,496	4,662,058	4,977,031	5,307,925
DSCR		1.6	1.6	1.6	1.7	1.7	1.7	1.8	1.9	2.0	2.2
Net debt to EBITDA		7.0	6.3	5.6	5.0	4.6	3.9	3.3	2.6	1.9	1.2
Debt on Equity		258.7%	225.5%	198.7%	175.0%	154.7%	136.4%	120.3%	106.0%	93.7%	82.9%

Source: JICA Data Collection Survey Team

As similar to the Best-effort Case, net debt to EBITDA and debt on equity are high at 8.5 and 294% respectively in 2030, posing a concern in payback capacity and financial position, however PPWSA will remain reasonably profitable, and cash and short-term investments remain positive.

12.7.6 Recommended Case (without Sludge Treatment) Analysis

For reference this Recommended Case (without Sludge Treatment) examines a case in which sludge treatment facilities are not installed. The summary of the results and comparison to the Recommended Case are illustrated below.

Table 12.7.6 Financial Forecast (Recommended Case (without Sludge Treatment))

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	224,774	245,000	249,000	287,000	293,000	300,000	321,714	401,087	408,660	517,376	644,400
Water Tariff	1,354	1,354	1,354	1,354	1,354	1,700	1,700	1,700	1,900	1,900	1,900
Total Income	324,368	357,602	360,340	417,765	440,688	603,892	599,915	734,791	835,958	1,045,123	1,291,119
Operating Profit	129,587	138,843	133,138	170,549	129,005	228,057	202,029	259,857	266,173	327,948	454,300
Operating Margin	40.0%	38.8%	36.9%	40.8%	29.3%	37.8%	33.7%	35.4%	31.8%	31.4%	35.2%
Net Profit	88,352	107,065	103,604	134,478	93,350	168,107	158,952	216,920	231,905	262,980	324,034
Net Margin	27.2%	29.9%	28.8%	32.2%	21.2%	27.8%	26.5%	29.5%	27.7%	25.2%	25.1%
Cash&ST Inv	118,155	116,707	89,042	238,085	308,463	901,249	1,693,255	2,417,980	1,983,449	1,262,147	909,809
Total Indebtedness	548,136	846,918	1,143,914	1,512,563	1,692,364	2,245,233	3,467,411	5,167,153	6,266,811	6,585,840	6,339,898
Equity	982,053	1,106,120	1,209,725	1,344,203	1,437,553	1,605,659	1,764,612	1,981,532	2,213,437	2,476,417	2,800,451
DSCR	1.6	4.3	5.4	6.6	4.2	4.9	4.6	3.4	2.7	2.5	2.3
Net debt to EBITDA	2.3	3.7	5.5	5.6	5.8	3.7	5.1	6.3	8.4	8.0	6.4
Debt on Equity	55.8%	76.6%	94.6%	112.5%	117.7%	139.8%	196.5%	260.8%	283.1%	265.9%	226.4%
(KHR '000 000)		2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production		723,973	730,546	737,119	739,855	739,855	739,855	739,855	739,855	739,855	739,855
Water Tariff		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
Total Income		1,443,337	1,457,062	1,470,851	1,477,420	1,437,409	1,437,197	1,437,006	1,436,834	1,436,679	1,436,540
Operating Profit		557,496	572,413	585,753	592,125	570,917	579,826	587,758	594,780	600,935	606,245
Operating Margin		38.6%	39.3%	39.8%	40.1%	39.7%	40.3%	40.9%	41.4%	41.8%	42.2%
Net Profit		325,476	350,527	377,071	396,333	393,391	413,729	433,965	453,620	472,583	491,022
Net Margin		22.6%	24.1%	25.6%	26.8%	27.4%	28.8%	30.2%	31.6%	32.9%	34.2%
Cash&ST Inv		1,191,811	1,569,646	1,891,255	2,215,531	2,510,412	2,846,238	3,203,090	3,569,690	3,960,575	4,370,323
Total Indebtedness		6,042,773	5,719,946	5,403,139	5,094,452	4,794,507	4,503,060	4,232,184	3,970,383	3,731,906	3,511,302
Equity		3,125,927	3,476,454	3,783,420	4,104,339	4,418,463	4,753,514	5,104,734	5,471,561	5,853,420	6,249,926
DSCR		1.9	1.9	1.9	2.0	2.0	2.1	2.2	2.3	2.5	2.7
Net debt to EBITDA		5.0	4.3	3.7	3.0	2.5	1.8	1.1	0.4	-0.3	-1.0
Debt on Equity		193.3%	164.5%	142.8%	124.1%	108.5%	94.7%	82.9%	72.6%	63.8%	56.2%

Difference

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	0	0	0	0	0	0	0	0	0	0	0
Water Tariff	0	0	0	0	0	0	0	0	0	0	0
Total Income	0	0	0	0	0	0	0	0	0	0	0
Operating Profit	0	0	0	0	709	1,541	8,446	20,426	37,054	57,733	73,036
Operating Margin	0.0%	0.0%	0.0%	0.0%	0.2%	0.3%	1.4%	2.8%	4.4%	5.5%	5.7%
Net Profit	0	0	0	0	-985	-581	3,661	14,446	29,171	52,348	76,929
Net Margin	0.0%	0.0%	0.0%	0.0%	-0.2%	-0.1%	0.6%	2.0%	3.5%	5.0%	6.0%
Cash&ST Inv	0	0	0	-93,497	-106,283	-188,890	-252,935	-316,087	-199,856	138,303	383,442
Total Indebtedness	0	0	0	-93,497	-193,480	-387,593	-660,357	-1,032,957	-1,347,232	-1,424,059	-1,383,667
Equity	0	0	0	0	-985	-1,565	2,096	16,542	45,713	98,061	174,990
DSCR	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.3	0.3	0.3	0.3
Net debt to EBITDA	0.0	0.0	0.0	0.0	-0.4	-0.6	-1.2	-1.7	-2.4	-2.4	-2.1
Debt on Equity	0.0%	0.0%	0.0%	-7.0%	-13.4%	-24.0%	-37.7%	-54.8%	-68.1%	-70.8%	-67.8%

(KHR '000 000)	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production	0	0	0	0	0	0	0	0	0	0
Water Tariff	0	0	0	0	0	0	0	0	0	0
Total Income	0	0	0	0	0	0	0	0	0	0
Operating Profit	73,805	69,931	66,292	62,859	59,595	56,491	53,539	50,732	48,062	45,522
Operating Margin	5.1%	4.8%	4.5%	4.3%	4.1%	3.9%	3.7%	3.5%	3.3%	3.2%
Net Profit	100,897	99,157	96,860	94,322	91,958	89,756	87,708	85,808	84,047	82,421
Net Margin	7.0%	6.8%	6.6%	6.4%	6.4%	6.2%	6.1%	6.0%	5.9%	5.7%
Cash&ST Inv	497,550	580,621	643,718	706,154	767,716	828,437	888,369	947,573	1,006,107	1,064,031
Total Indebtedness	-1,329,778	-1,272,816	-1,217,469	-1,164,278	-1,113,365	-1,064,666	-1,018,095	-973,561	-930,974	-890,250
Equity	275,887	375,044	452,073	527,022	600,116	671,480	741,238	809,504	876,389	942,000
DSCR	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5
Net debt to EBITDA	-1.9	-1.9	-2.0	-2.0	-2.1	-2.1	-2.1	-2.2	-2.2	-2.2
Debt on Equity	-65.4%	-60.9%	-55.9%	-50.8%	-46.2%	-41.7%	-37.4%	-33.5%	-29.9%	-26.7%

Source: JICA Data Collection Survey Team

In this case, CAPEX and depreciation cost will decrease and operating margin will increase by 5.7% point in 2030 improving profitability and financial stability.

12.7.7 Scale-down Case Analysis

For reference this Scale-down Case will examine the scope of the projects to be financially feasible under the current water tariff (KHR1,354/m³) and 3% interest rate. It concludes that Koh Norea and Ta Mouk I&II will not be feasible, and total production capacity would decrease by 550,000m³/day. The summary of the results is illustrated below.

Table 12.7.7 Financial Forecast (Scale-down Case)

(KHR '000 000)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Production	224,774	245,000	249,000	287,000	293,000	300,000	321,714	401,087	408,660	462,626	516,650
Water Tariff	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354
Total Income	324,368	357,602	360,340	417,765	440,688	496,411	484,929	592,369	607,080	682,888	760,855
Operating Profit	129,587	138,843	133,138	170,549	128,271	127,913	89,760	127,323	97,187	108,911	141,398
Operating Margin	40.0%	38.8%	36.9%	40.8%	29.1%	25.8%	18.5%	21.5%	16.0%	15.9%	18.6%
Net Profit	88,352	107,065	103,604	134,478	94,371	89,822	66,192	91,291	64,198	54,146	62,271
Net Margin	27.2%	29.9%	28.8%	32.2%	21.4%	18.1%	13.6%	15.4%	10.6%	7.9%	8.2%
Cash&ST Inv	118,155	116,707	89,042	334,975	415,685	786,016	761,454	925,954	522,398	243,999	32,720
Total Indebtedness	548,136	846,918	1,143,914	1,609,454	1,889,948	2,469,969	3,019,476	3,674,936	3,926,358	3,971,491	3,782,609
Equity	982,053	1,106,120	1,209,725	1,344,203	1,438,573	1,528,396	1,594,587	1,685,878	1,750,077	1,804,222	1,866,493
DSCR	1.6	4.3	5.4	6.6	4.1	3.8	3.1	2.4	1.7	1.6	1.5
Net debt to EBITDA	2.3	3.7	5.5	5.6	6.2	6.4	9.3	8.8	11.0	10.4	9.3
Debt on Equity	55.8%	76.6%	94.6%	119.7%	131.4%	161.6%	189.4%	218.0%	224.4%	220.1%	202.7%
(KHR '000 000)		2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Water Production		523,223	529,796	536,369	539,105	539,105	539,105	539,105	539,105	539,105	539,105
Water Tariff		1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354	1,354
Total Income		770,927	781,066	791,270	796,347	756,335	756,123	755,932	755,761	755,606	755,467
Operating Profit		138,831	144,044	148,171	147,544	121,071	125,065	128,416	131,178	133,380	135,030
Operating Margin		18.0%	18.4%	18.7%	18.5%	16.0%	16.5%	17.0%	17.4%	17.7%	17.9%
Net Profit		30,266	38,108	46,312	50,346	33,480	40,093	46,760	52,985	58,642	63,884
Net Margin		3.9%	4.9%	5.9%	6.3%	4.4%	5.3%	6.2%	7.0%	7.8%	8.5%
Cash&ST Inv		18,712	46,534	67,520	83,618	62,695	73,995	97,566	122,116	162,163	212,266
Total Indebtedness		3,579,102	3,360,849	3,146,334	2,936,193	2,730,613	2,529,438	2,344,892	2,165,647	2,006,114	1,861,003
Equity		1,896,759	1,934,867	1,973,558	2,014,641	2,038,052	2,071,450	2,110,191	2,153,824	2,201,869	2,254,025
DSCR		1.3	1.3	1.3	1.3	1.2	1.2	1.3	1.3	1.4	1.5
Net debt to EBITDA		8.8	8.3	7.9	7.5	7.7	7.2	6.7	6.2	5.7	5.2
Debt on Equity		188.7%	173.7%	159.4%	145.7%	134.0%	122.1%	111.1%	100.5%	91.1%	82.6%

Source: JICA Data Collection Survey Team

In this case, cash and short-term investments would be slightly negative in 2030 and 2031, indicating that there would be no more financial capacity to invest in Koh Norea and Ta Mouk I&II. Under the current water tariff and 3% interest rate more than half of the proposed projects (capacity basis) will not be financially viable.

12.7.8 Conclusion and Recommendation

In the Base Case scenario in which the water tariff remains the same as the current price the proposed projects would not be financially feasible. It is recommended that PPWSA will increase the water tariff to the KHR2,400/m³ target. PPWSA shall consult with financial institutions and/or development partners for better financing conditions and terms to improve profitability for sustainable operation and introduce PPP or equivalent schemes only where public funds are not enough to implement the proposed projects.