4.3 Comparative Study on Alternative Water Sources

4.3.1 Method of Comparison

(1) Alternative Sources

As discussed in the previous Section 4.2, Development Potential of Water Sources, four alternative water sources,

Alternative – 1 :Groundwater,
Alternative – 2 :West Baray,
Alternative – 3 :Siem Reap River, and
Alternative – 4 :Lake Tonle Sap,

are considered as potential water sources for future water supply in Siem Reap Town. Methodology and results of comparative study to select the most suitable water source from these potential water sources are described in this chapter. More detail explanation is available in Annex 4.3.1.

(2) Basis of Comparison

For the comparison, not only the costs of water source development but also the costs required for the respective water supply system are comprehensively considered and compared. These water supply systems were planned based on the capacity of 12,000 m^3/day which was projected in the previous section as Daily Maximum Water Demand in Year 2010.

In addition to the cost comparison, other criteria are also taken into account. Criteria for the comparison are described in the following sections.

(3) Criteria for Comparison

For the selection of the best water source, the following criteria are considered.

1) Lower Cost

a) Investment Costs

Investment cost should be economically minimized. Costs required for water source development and construction costs of water supply system are calculated for each alternative. Cost for distribution trunk main to the center of the town is included and the cost for distribution network in the service area is excluded from the relative investment cost because the cost is common to all alternatives.

b) Operation and Maintenance Costs

Operation cost such as electricity cost, chemical cost, and salary are calculated for each water supply system. Maintenance cost is also calculated as 1% of total construction costs.

For comparison, total costs in terms of Net Present Value were calculated from the cost of water source development, water supply facility construction and operation and maintenance. Discount rate for NPV is 10% and duration of NPV calculation is 30 years. (Figure 4.3.1)

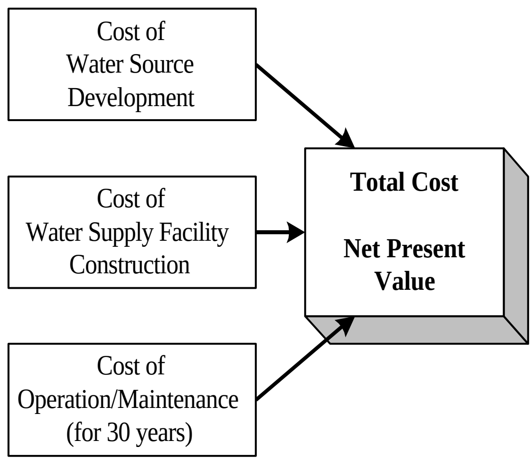

Figure 4.3.1 Net Present Value

2) Easy Operation and Maintenance

System operation should be simple and be sustainable without complicated maintenance work. Water source which will make water supply facility simple is the most suitable.

3) Less Impact to Angkor Heritage

Impact to the Angkor heritage which will be caused by water source development or by construction of water supply facilities should be minimized. Water source which will not cause significant adverse side effects should be selected.

4) Reliability

Water supply system should be operated continuously without termination. In this aspect, water source of water supply system should have high reliability even in the drought season.

5) Stable and Suitable Water Quality

Fluctuation of the raw water quality will make water treatment difficult in terms of operation and will increase cost of treatment system operation. Operation cost, specially chemical costs, will be minimized in case the raw water quality is suitable for potable water supply.

6) Flexibility of the System

Water supply system should have flexibility to overcome unforeseen condition.

7) Less Impact to Environment

In the selection process of the most suitable water source, proper consideration is given in order to have less environmental impacts. The major criteria are social environment, natural environment and pollution. Environmental impacts expected from the development of each alternative are carefully examined and utmost efforts are given to select an alternative with less impact.

4.3.2 Alternatives

Water supply facilities for four alternative water sources are shown on Figure 4.3.2.

(1) Alternative – 1 : Groundwater System

As described in the previous section, water quality of the groundwater in the southern area of the Siem Reap Airport is suitable and stable as a source of water supply. No treatment will be required and water will be supplied directly after disinfection by liquid chlorine. Because of no treatment, operation and maintenance of the system is much easier comparing with other alternative sources, and it will result in low operation and maintenance cost.

Groundwater level should be always monitored and adequate abstraction rate should be reviewed to avoid excessive drawdown. At the same time, effect to Angkor heritage should be monitored continuously to avoid any damage to the heritage.

The facilities of the groundwater system will consist of well field, connecting pipelines, receiving well, clear water reservoir, distribution pumping station, and disinfection facilities.

(2) Alternative – 2 : West Baray System

Because of the huge capacity of the West Baray, water quality of the baray will not fluctuate and will remain very stable. It will result easier operation and maintenance of the treatment plant comparing with other surface water systems.

Construction of the water treatment plant is necessary since water from the West Baray contains turbidity. Therefore, higher investment costs, higher operation and maintenance costs, and more complicated operation will be required compared with the groundwater system.

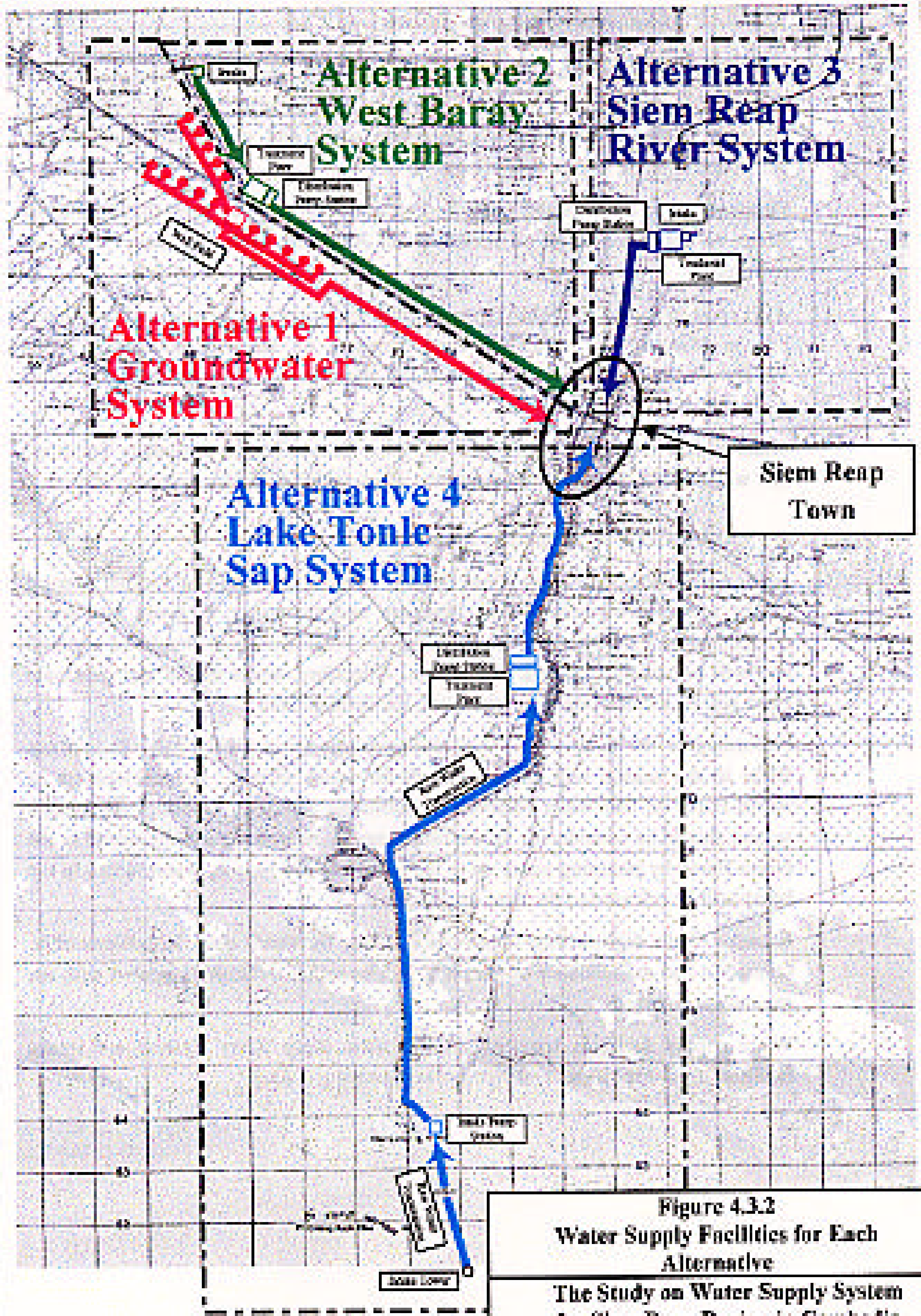

Figure 4.3.2
Water Supply Facilities for Each Alternative

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Rehabilitation of the West Baray is required to improve its reliability as a source of water supply system. As rehabilitation work, tree cutting and clearing on inner slope of dikes, embankment rehabilitation work and gravel metalling of the inspection road on the dikes are required.

Furthermore, to assure stable water inflow to the West Baray from the Siem Reap River, rehabilitation work on French Weir, American Weir, and Takev Canal is required.

At present, water of the West Baray is used for irrigation purpose and controlled by the Ministry of Agriculture and Ministry of Water Resources. When Waterworks takes its raw water from the West Baray, close coordination with these ministries is required.

Water supply facilities required for the West Baray System are intake facilities, raw water conveying facilities, treatment plant, and distribution pumping station.

(3) Alternative – 3 : Siem Reap River System

In the case of the Siem Reap River System, intake facility will be located at north of the town, in between Angkor heritage and the town, to avoid raw water contamination by wastewater from the town. Treatment plant should be required and will be constructed near the intake. Therefore, water intake and treatment plant will be located near from the town, the demand area.

According to the hydrological analysis, possible water yield of the Siem Reap River in dry season will not be enough for water supply. Re-development of North Baray as raw water reservoir to substitute raw water shortage in drought season should be considered. In the rainy season, river water will be stored in the North Baray by pumping water up to the baray. In dry season, water stored in the baray will be released to the river by gravity.

Because of the high turbity, construction of the treatment plant is indispensable. Operation and maintenance of the plant will be rather difficult compared with the groundwater system.

Water supply facilities required for the Siem Reap River System are intake facilities, treatment plant, and distribution pumping station.

(4) Alternative – 4 : Lake Tonle Sap System

From a hydrological viewpoint, the intake site should be located below approximately EL. 0.7 m, which is 20-year return period minimum water level in the dry season. Therefore, the available intake site is recommended to be located at least 4 km offshore from the existing boat station, the shoreline at the lowest level. Also from the water quality viewpoint, water near the boat station is contaminated by wastewater from boats and habitat nearby. Therefore, intake point should be located far from the boat station.

Water supply facilities required for the Lake Tonle Sap System are intake facilities, raw water conveying facilities, treatment plant, and distribution pumping station.

4.3.3 Cost Comparative Study

Four water supply systems for the respective water sources, preliminary cost estimation of direct construction costs as well as operation and maintenance (O & M) costs of four alternatives are estimated and compared as follows.

(1) Basis of Cost Estimation

Price Level: Base year for the cost estimation is 1999 and all costs are shown in US$.

Unit Cost: Unit cost data in this cost estimation are collected from government offices, local consultants and manufacturers. It should be noted that the costs used for the estimation are only direct costs unless otherwise indicated.

(2) Direct Construction Cost

Based on preliminary facility design of water supply system for four alternatives and unit construction costs, preliminary direct construction costs for each alternative are estimated as shown in Table 4.3.1 and Figure 4.3.3.

Land price of the prospective sites of well houses, pump stations, treatment plants and other related facilities are estimated based on the information of PDIME Siem Reap office.

As a result of comparison of the direct construction costs and land acquisition costs, the Alternative –1 : Groundwater System is the most economical.

Table 4.3.1 Summary of Direct Construction Cost and Land Acquisition Cost

(× 1,000 US$)

Description		Alternative			
		1 Groundwater System	2 West Baray System	3 Siem Reap River System	4 Lake Tonle Sap System
A	Direct Construction Cost				
	Well/Intake	1,765	582	579	1,921
	Raw Water Conveying		884		4,669
	Treatment Plant	1,943	4,672	4,659	4,633
	Distribution Trunk Main	2,359	2,359	1,112	1,264
	Water Source Development		1,070	5,995	
	Subtotal A	6,067	9,567	12,345	12,487
B	Land Acquisition	250	388	750	775
Grand Total		**6,317**	**9,955**	**13,095**	**13,262**
Comparison		**100%**	**158%**	**207%**	**210%**

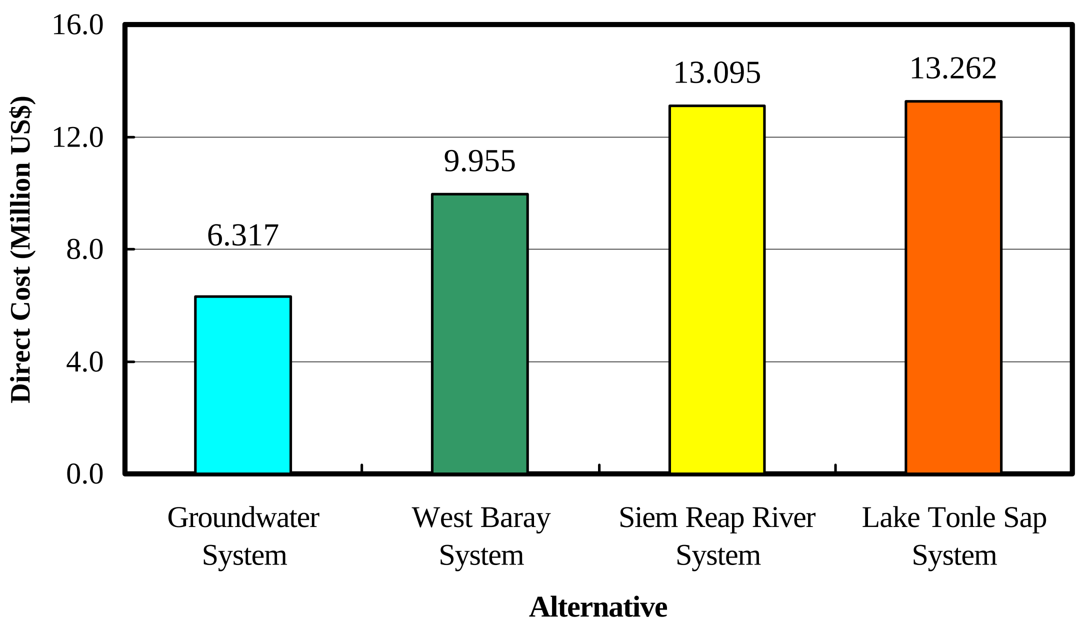


Figure 4.3.3 Comparison of Construction Cost (Direct Cost Only)

(3) Operation and Maintenance Costs

From the unit costs of electric power cost, chemical cost, personnel cost and maintenance cost, total unit operation and maintenance costs was calculated as shown on Table 4.3.2 and Figure 4.3.4.

The Alternative – 1 : Groundwater System has the lowest operation and maintenance costs.

Table 4.3.2 Operation and Maintenance Costs

Alternative		Operation and Maintenance Costs	
		US$/year	US$/m^3
1	**Groundwater System**	**263,773**	**0.072**
2	West Baray System	299,567	0.082
3	Siem Reap River System	322,304	0.088
4	Lake Tonle Sap System	359,008	0.098

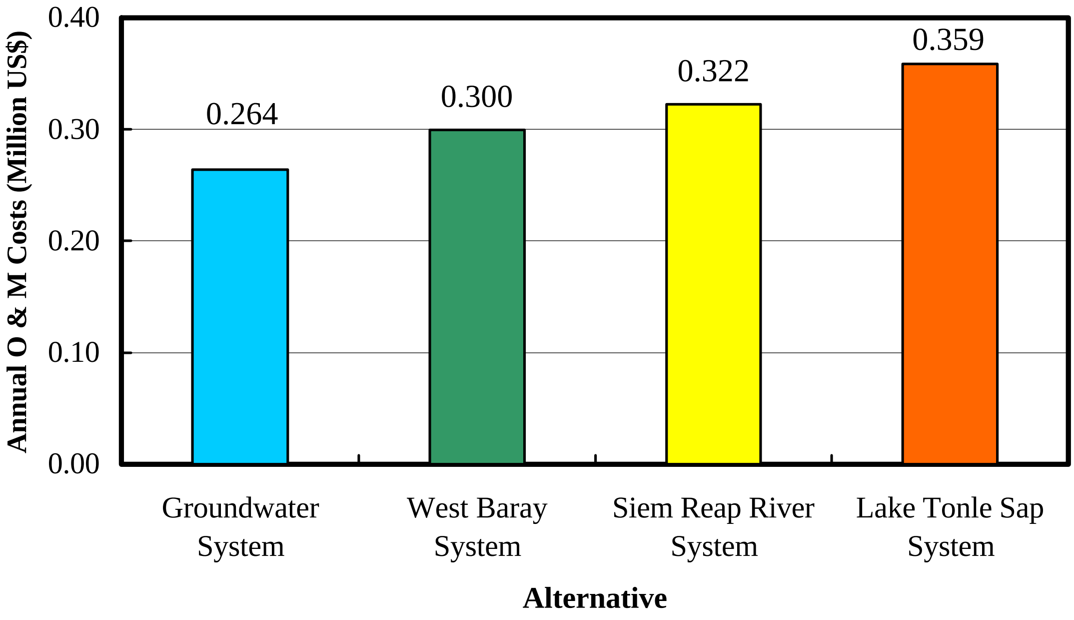


Figure 4.3.4 Comparison of Annual Operation and Maintenance Costs

(4) Results of Cost Comparison

The direct construction costs, which includes construction cost of water source development and water supply facilities, and operation and maintenance costs of respective alternatives are combined and compared by net preset value.

Results of net present value calculation are shown on Table 4.3.3 and Figure 4.3.5. The Alternative – 1 : Groundwater System shows the lowest present value.

Table 4.3.3 Comparison of Net Present Value

Alternative		Net Present Value (US$)	Comparison
1	**Groundwater System**	**7,508,438**	**100%**
2	West Baray System	11,246,262	150%
3	Siem Reap River System	14,260,995	190%
4	Lake Tonle Sap System	14,626,343	195%

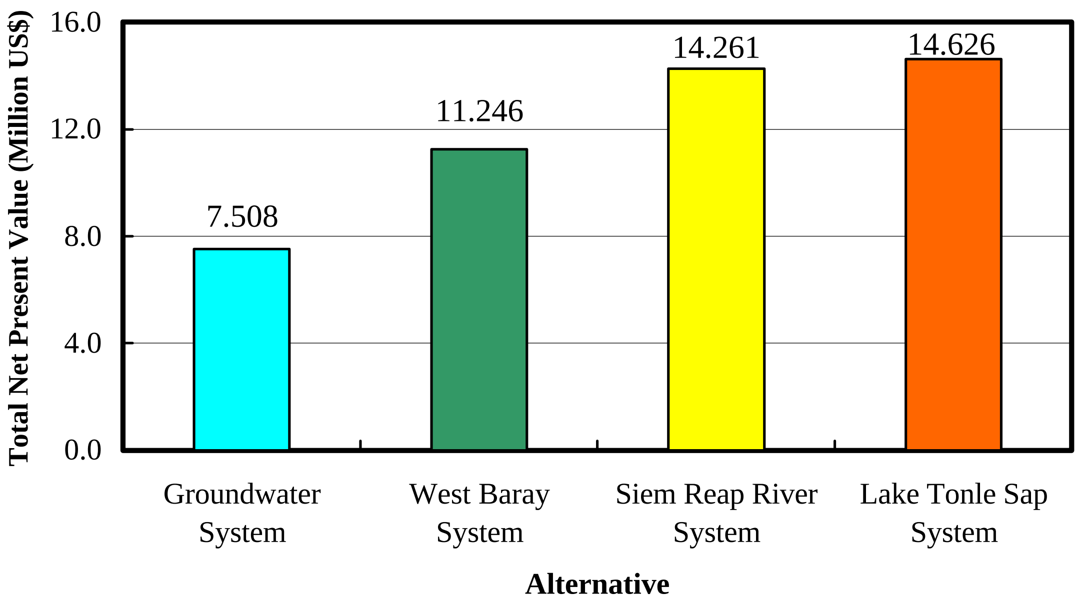


Figure 4.3.5 Comparison of Total Net Present Value
(Discount Rate=10%, 30 Years)

4.3.4 Comprehensive Comparison and Selection of the Best Alternative

In the previous section, direct construction cost and operation/maintenance costs were estimated and compared. As a results of cost comparison, the Alternative – 1 : Groundwater System is found to be the most economical option.

Cost is one of the most important criteria for the comparative study. However for the selection of the most suitable water source, the following criteria are also considered.

1) Costs
2) Easy Operation and Maintenance
3) Less Impact to Angkor heritage
4) Reliability
5) Stable and Suitable Water Quality
6) Flexibility of the System
7) Less Impact to Environment

Each alternative is evaluated by this criteria and the results of the evaluation are shown on Table 4.3.4.

Table 4.3.4 Results of Evaluation

Criteria	Alternatives			
	Alternative – 1 Groundwater System	Alternative - 2 West Baray System	Alternative - 3 Siem Reap River System	Alternative - 4 Lake Tonle Sap System
Costs	◎	○	△	×
Easy Operation and Maintenance	◎	○	△	×
Less Impact to Angkor heritage	○	○	○	◎
Reliability	◎	○	○	◎
Stable and Suitable Water Quality	◎	◎	○	○
Flexibility of the System	◎	○	○	○
Less Impact to Environment	◎	○	○	×

Note : Good ◎ <- ○ -- △-> × Bad

From the results of evaluation shown above, Alternative – 1 : Groundwater System is the most suitable alternative and recommendable as a water source for the Siem Reap Water Supply System.

However, for future water supply system after the Year 2010, West Baray System, Siem Reap River System, and Lake Tonle Sap System including further development of groundwater should be considered as an option.

4.4 Past and Present Public Water Supply System

4.4.1 Introduction

Public piped water supply system in Siem Reap Town is under responsibility of the Siem Reap Waterworks, which is one of the waterworks controlled by the Ministry of Industry, Mines, and Energy (MIME). It should be noted that the Siem Reap Waterworks does not have direct organizational relation with the Provincial Government of Siem Reap.

The first public piped water supply system was established in the 1930's by French aid. The system so called "Old French System" was consisted of treatment plant taking its raw water from the Siem Reap River and small-scale distribution system. The treatment plant was constructed on the corner of crossing National Road No. 6 and Siem Reap River.

The second system was constructed in the 1960's by American aid and the Old French System was abandoned at this time. This Old American System also took its raw water from the Siem Reap River. The treatment plant was constructed in the premises of the Old French System treatment plant. Distribution system was expanded to cover the central part of the Siem Reap Town. This system had been operated until March 1995; water treatment was terminated and the waterworks stopped its public water supply services because of deterioration of raw water quality of the Siem Reap River and deterioration of the facilities.

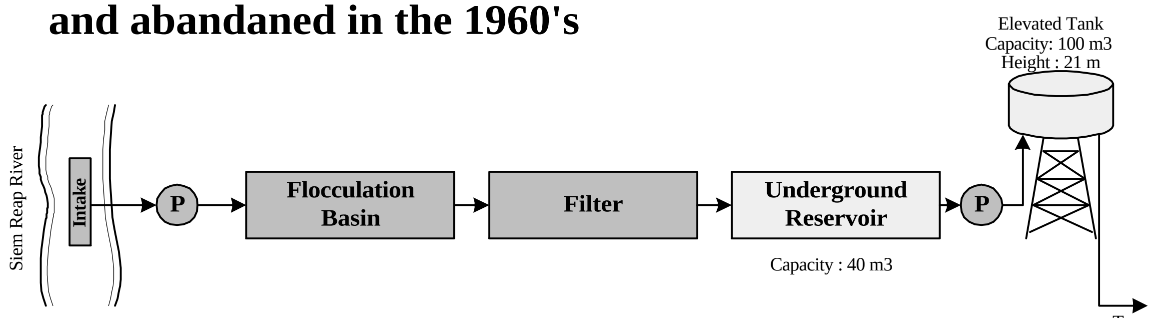
MIME commenced construction of a new water supply system using groundwater in 1995 financed by French aid. Two deep wells were dug in the existing treatment plant. However, groundwater from these two deep wells contains high iron and it was not suitable for drinking. To remove the high iron contents, aeration facility and pressure filters were additionally installed. This New French System was completed in September 1998, and finally the Siem Reap Waterworks started its water supply services from the end of July 1999.

Further detailed information are shown in Annex 4.4.1 and Annex 4.4.2.

4.4.2 Old French System

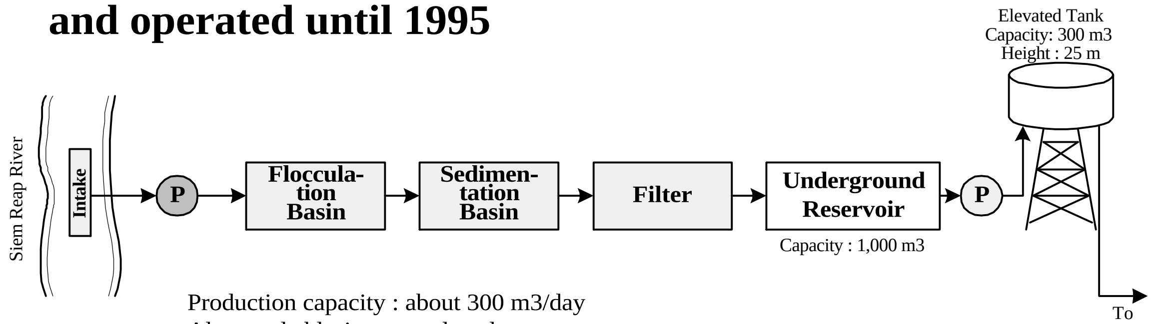
Details of the Old French System, which was constructed in the 1930's, are not known now but its treatment system seems to be as shown on Figure 4.4.1 according to interview from the staff of the Siem Reap Waterworks.

Old French System constructed in the 1930's and abandaned in the 1960's



Production capacity of this system is unknown. Alum and chlorine seem to be dozed.

Old American System constructed in the 1960's and operated until 1995



Production capacity : about 300 m3/day
Alum and chlorine were dozed.
Operation was terminated in 1995 because of deteriorated water quality of the Siem Reap River.

- Structure is demolished
- Structure exists but not used/operated
- Structure which is used/operated as a part of a New French System

The Study on Water Supply System for Siem Reap Region in Cambodia	Figure 4.4.1 Schematic Flow of Treatment System (Old French System and Old American System)
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Raw water was taken from the Siem Reap River. Intake structure was constructed about 50 m upstream from the bridge on the National Road No. 6. Raw water was pumped up to flocculation basin and coagulated by dozing alum. After flocculation basin, water was conveyed to filtration basin and filtered water was stored in underground reservoir. Treated water was distributed by distribution pumps through elevated tank of which height is 21 m. Production capacity of the plant is unknown.

All structures except the underground reservoir and the elevated tank were demolished when the Old AMERICAN System was constructed, therefore details of each facility could not be investigated. The reservoir and the elevated tank still exist but they are not used now.

Treated water was distributed to Grand Hotel and houses in very limited area near the plant. Drawings of the distribution network do not exist anymore.

4.4.3 Old American System

The Old American System was constructed by demolishing the Old French System in 1960's financed by American aid. Treatment system was as shown also on Figure 4.4.1. The plant capacity was about 300 m^3/day. However, actual treatment capacity was less than 150 m^3/day according to the information from the Waterworks. Raw water was taken from the Siem Reap River as same as the Old French System through a new intake facility constructed about 100 m upstream from the former intake. Raw water was transmitted by intake pumps to up down flow type flocculation basin. Alum was dozed as a coagulant. Sedimentation basin had 4 separated basins and then water was transmitted to filters. Filter was rapid sand filtration system and there were two filter beds. Filtered water was conveyed to underground reservoir of which capacity was 1,000 m^3. Treated water was pumped up to the new-elevated tank and sent to distribution network.

This Old American System had been operated until March 1995. Operation of the Plant was terminated in 1995 because of deterioration of raw water quality of the Siem Reap River and because facilities became too old to operate.

Distribution network was constructed at the same time of the construction of the treatment plant. This distribution network covers rather larger area than the Old French System but still limited in the central part of the Siem Reap Town. When the distribution pipelines were installed, pipelines installed under the Old French

System were completely abandoned.

Range of diameter was 100 mm to 250 mm and the material of the distribution pipeline was ACP. Alignment of the distribution network is shown on Figure 4.4.2. Number of connection supplied by the Old American System was 207 in total in 1995 and these all connection were not equipped with water meter.

4.4.4 New French System

After termination of the Old American System, MIME constructed the new groundwater system using French aid (CFD) fund in the existing treatment plant premises. Construction was completed in September 1998 and was ready for operation. Schematic system flow is shown on Figure 4.4.3.

MIME finally quit using surface water from the Siem Reap River as a source of water supply and it changed water source to deep wells. This New French System consists of two deep wells, aeration basin, two pressure filters, distribution pumps, lime feeding facilities and chlorine gas disinfection facilities. Clear water reservoir and elevated tank, which were constructed under the Old American System, are used in this New System.

Two deep wells have same specifications and depth of the each well is about 60 m and diameter of casing is 400 mm. Capacity of groundwater abstraction from each deep well is 60 m^3/h (1,440 m^3/day or 16.7 l/sec). These two wells are operated alternately, not operated simultaneously.

Quality of groundwater is shown in Table 4.4.1. As shown in the table below, concentration of iron is high and pH is low. To remove the iron contents, this System employed aeration system and pressure filter. Lime feeding facilities were installed for pH control before the aeration system.

Table 4.4.1 Quality of Groundwater

Parameter	Unit	Concentration
pH	-	5.2 to 5.61
Conductivity	μS/cm	48 to 63
Turbidity	NTU	0
Hardness	mg/l $CaCO_3$	4.8 to 5.0
TDS	mg/l	24 to 31.6
SS	mg/l	0
Fe	mg/l	1.42 to 1.89
Manganese	mg/l	0
NH_4^+	mg/l	0 to 0.08
COD($KMnO_4$)	mg/l	1.34 to 1.89

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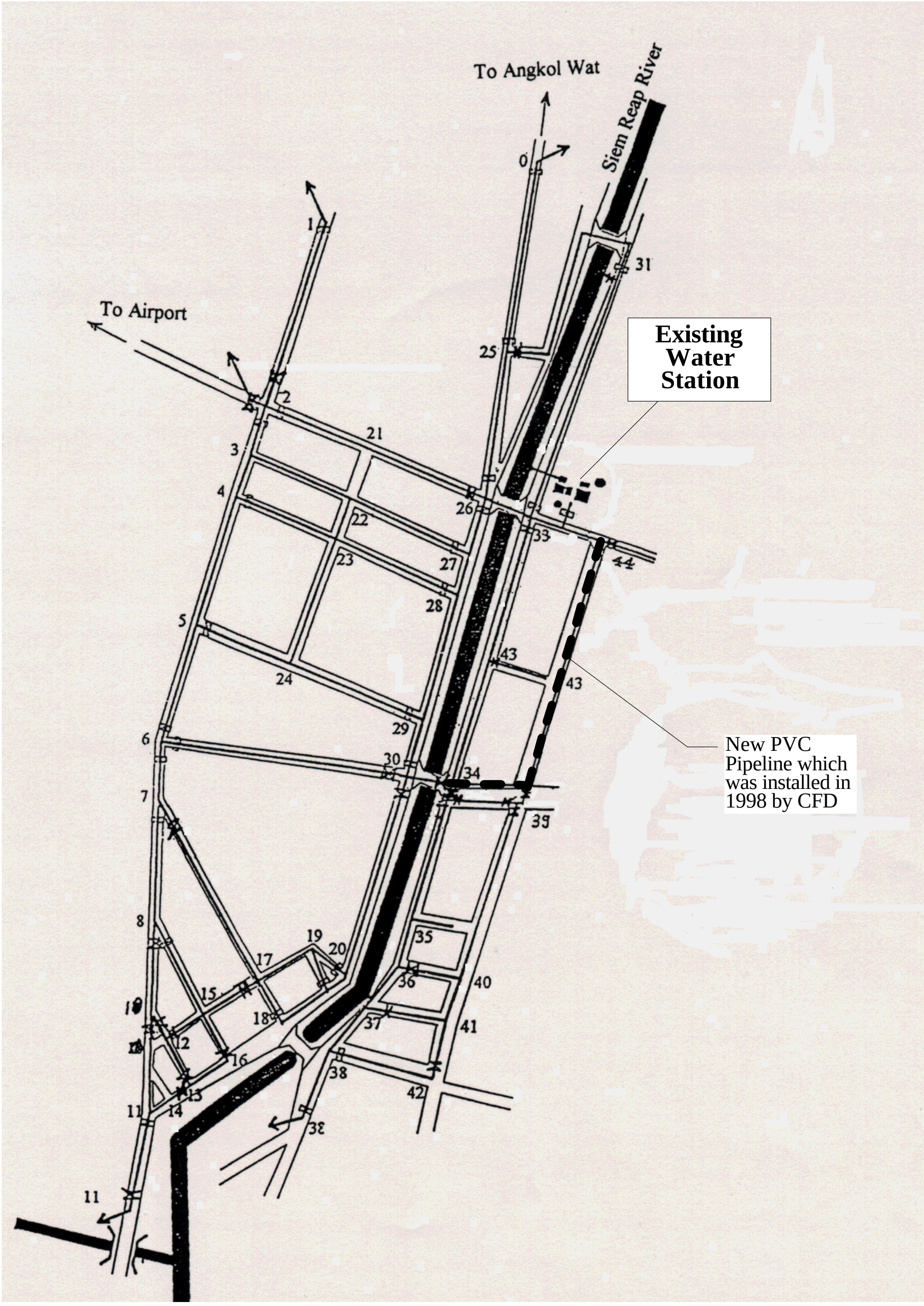

The Study on Water Supply System for Siem Reap Region in Cambodia	Figure 4.4.2 Existing Distribution Network
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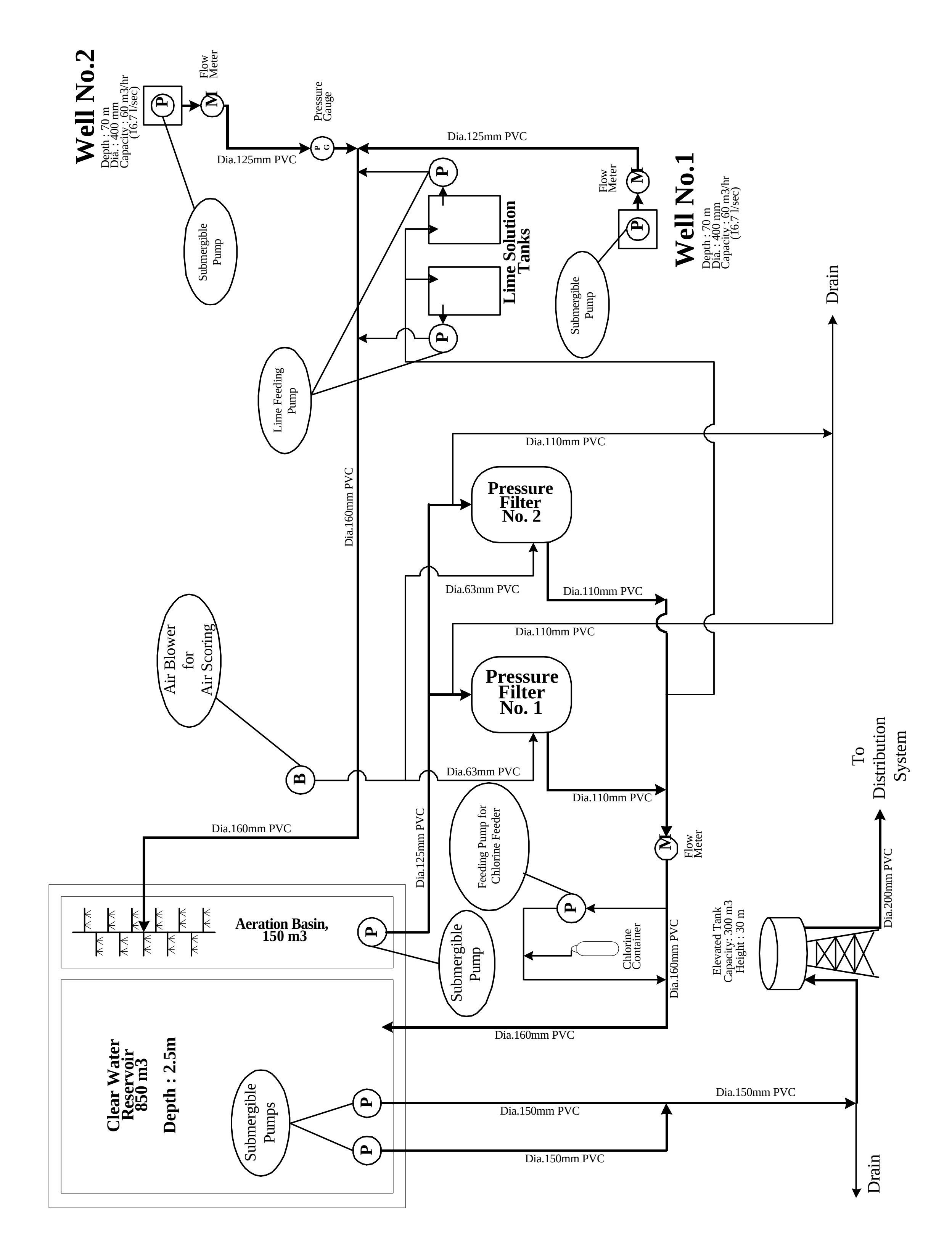

The Study on Water Supply System for Siem Reap Region in Cambodia	**Figure 4.4.3 Schematic System Flow of New French System**
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Aeration basin is constructed using the part of the existing underground clear water reservoir. Capacity of the aeration basin is 150 m^3 and spray type aerators are installed in half portion of the basin. After the aeration, there are two steel made pressure filter tanks of which diameter is 1,800 mm and height is 1,400 mm.

The underground clear water reservoir was constructed and used under the Old American System. Original capacity was 1,000 m^3. Part of the reservoir is used as the aeration tank and current capacity is reduced to 850 m^3 and depth is 2.5 m.

Filtered clear water is stored in this reservoir and pumped up to the elevated tank for distribution by two submergible pumps in the reservoir. One pump is for operation and the another is stand-by. The elevated tank, which was constructed under the Old American System, is used in the new system. Capacity of the tank is 300 m^3 and height is 25 m.

When the New French System was constructed, CFD checked all distribution network pipeline, and in the case they found broken pipe, they repaired the pipe. There was no expansion works except one pipe additionally installed which is shown on Figure 4.4.2.

At the same time of pipeline repairing works mentioned above, installation of new connections and rehabilitation on existing 207 connections were implemented. As rehabilitation works, local steel made saddles, which were heavily corroded, were replaced with new cast iron made saddles. Total number of connection became 409.

4.4.5 Recent Inauguration of the New French System

(1) Inauguration of the New French System

Although the New French System was completed in September 1998, MIME did not approve its inauguration because MIME considered that the Waterworks in Siem Reap Town could not afford to the electrical cost for operation.

In 1999, PDIME Siem Reap received a grant of US$ 299,000 from UNDP to finish the remaining work of the New French System, rehabilitation of distribution network, and administrative development. Finishing work of the plant was completed, however, rehabilitation work of distribution network had not been completed.

After that, Waterworks continues its effort to rehabilitate the distribution networks.

This pipe rehabilitation work had been conducted from June 1999, and finally Waterworks started its water supply services from the end of July 1999 even though distribution network rehabilitation work had not been completed and there still many problems on distribution network.

During this pipe rehabilitation work, PDIME has been negotiated with public electric supply about concession electric rate and PDIME finally received concession rate, discounted from US$ 0.23/kWh to US$ 0.195/kWh.

(2) Modification of Treatment Flow

The Siem Reap Waterworks started operation of the New French System from the end of July. Unfortunately, the Waterworks could not continue its operation with original set-up.

There were several reasons of the modification and the most significant reason was high iron concentration of the groundwater. Concentrations of iron in groundwater from the Well No. 1 and 2 sometimes reached 11 mg/l and 3 mg/l, respectively. Because of the high iron contents, original spray type aeration system could not oxidize iron contents effectively.

Finally the Waterworks decided not to use the original aeration basin and the Waterworks modified its treatment flow. In August 1999, the Waterworks installed fountain type aerator on the previous sedimentation basin, which was constructed in 1960s and had not been used from 1995. Location of lime solution feeding for pH control before the aeration was shifted to the previous sedimentation basin accordingly.

This modified treatment flow is shown on Figure 4.4.4. As shown on this Figure, in addition to the modification of aeration system, the Waterworks installed two distribution pumps to save energy costs. It should be noted that operation of the new aeration system is not continuoAmericannd operated in batch system.

Concentration of iron in treated water after these process modifications is 0.1 to 0.3 mg/l and the quality is acceptable for the customers. Although the quality of treated water is much improved by this modification; plant capacity becomes low to 500 m^3/day against design capacity of 1,440 m^3/day because of the batch operation.

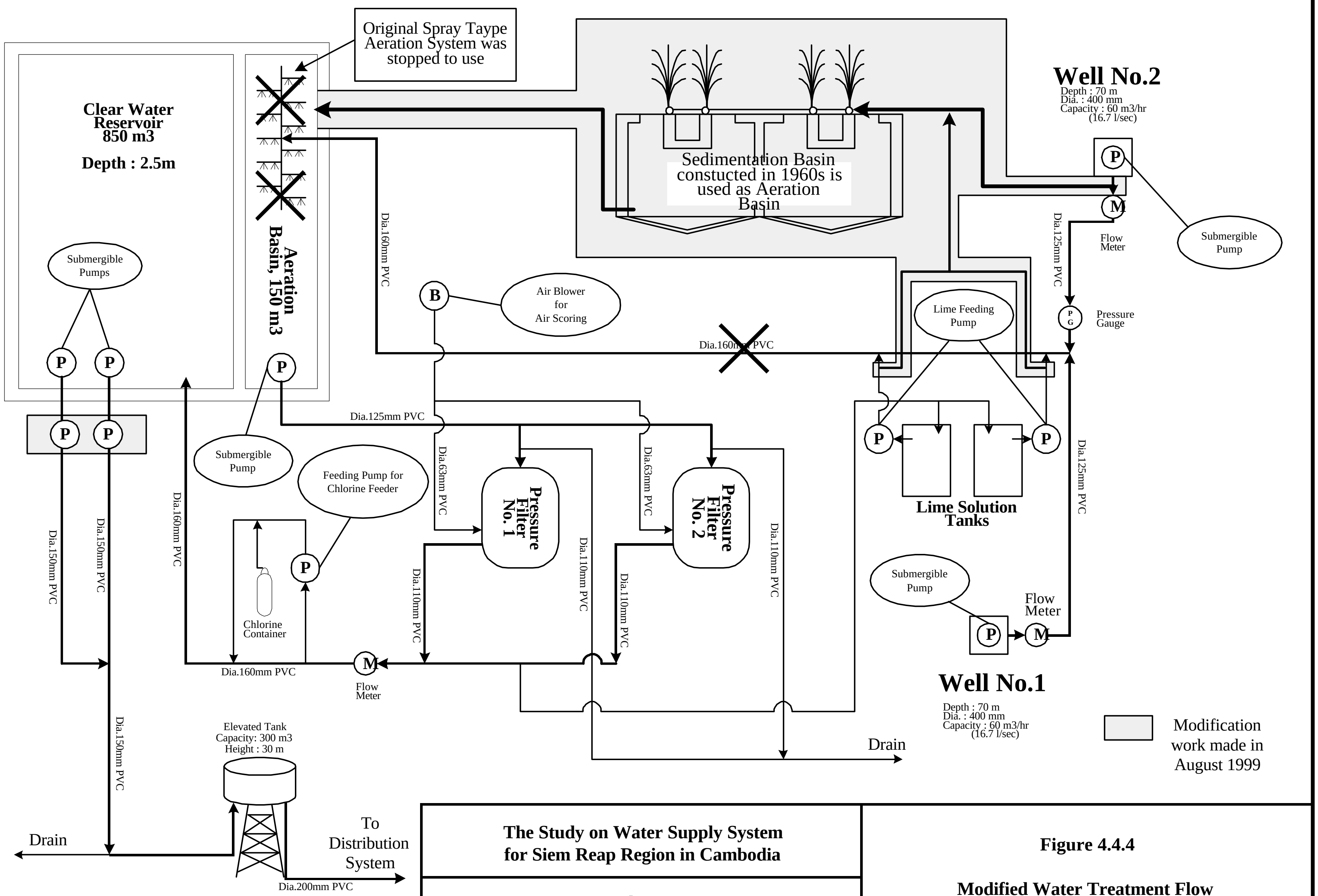

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Figure 4.4.4

Modified Water Treatment Flow

To increase treatment capacity, the Waterworks has a plan to expand its aeration system occupying previous filter basin. According to the estimation of the Waterworks, capacity will be increased up to 800 m^3/day by the expansion.

(3) Increasing House Connection

In 1996, after construction of the New French System, new house connections were installed and total number of house connection in 1996 was 382, total 409 – 27 missing connection, including old house connection which had been installed from 1960's to 1995.

Customers of these 382 house connections were requested to resister again by official announcement from the Waterworks on July 19,1999 just before the inauguration of the New French System on July 28, 1999 to resume public water supply service.

Total number of registered connection has been increased and became 260 connections in October 1999.

4.4.6 Selection of Pipelines to be Replaced

(1) Condition of Existing Distribution Network

Range of diameter of the existing distribution network, which was constructed in 1960's, is 100 mm to 250 mm and the dominant material of the distribution pipeline is ACP. PVC material was used in very limited pipeline which was recently installed by AFD in 1995. Breakdown of the network by its diameter and material is shown on Table 4.4.2. Alignment of the existing distribution network is shown on Figure 4.4.2 and diameter and length of each pipeline is shown on network diagram, Figure 4.4.5.

Table 4.4.2 Length of Existing Distribution Network

Diameter (mm)	Length (m)
250 ACP	509
200 ACP	1,646
150 ACP	4,075
150 PVC	148
100 ACP	5,227
100 PVC	452
Total	**12,057**

Using the pipe network diagram shown on Figure 4.4.5, hydraulic analysis of the existing distribution network was conducted. According to the results of the analysis, capacity of the exiting network is enough to distribute water which is produced by the New French System.

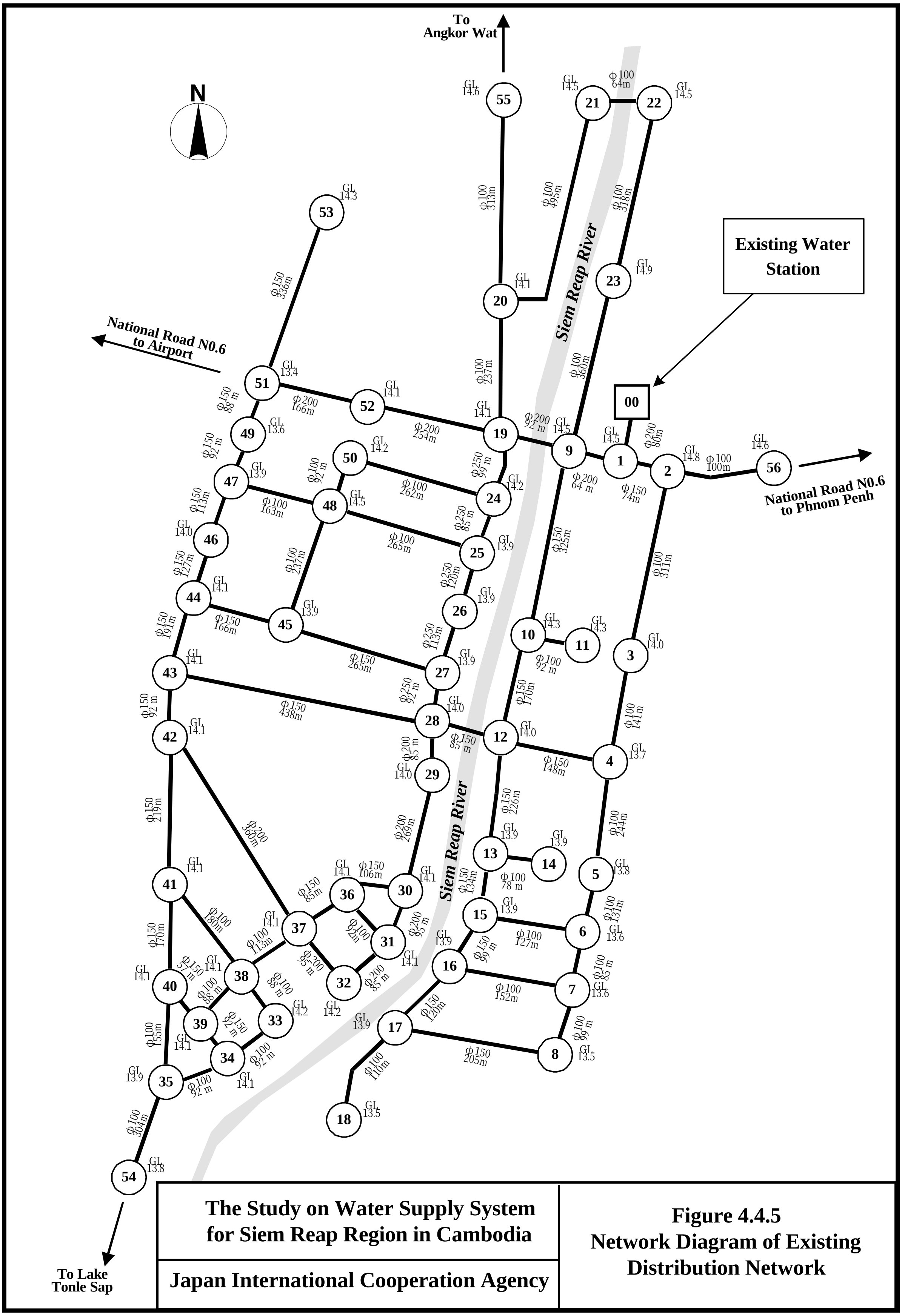

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Figure 4.4.5
Network Diagram of Existing Distribution Network

When the New French System was constructed, AFD checked all distribution network pipeline. Although AFD repaired some pipelines, but the condition of distribution network is still not good according to the information from Waterworks. After the AFD's repairing work, many construction activities have been taken place such as electric cable installation along the distribution pipelines. These construction works must damage water pipeline according to the staff of the Waterworks.

Under such situation, Waterworks has continued its effort to rehabilitate existing distribution pipeline, and, Waterworks is still having a very busy time to repair pipelines every day.

(2) Selection of Pipelines To Be Replaced

It is apparent that rehabilitation of the existing distribution network is indispensable considering current situation. Considering the age of pipes, pipe replacement will be recommended.

For the selection of the pipelines to be replaced, following data and information were considered.

1. Results of leakage survey conducted by AFD
2. Record of location of leak repaired by the Waterworks
3. Record of location of house connection repaired by the Waterworks
4. Density of house connection
5. Pipelines where Waterworks experienced difficult maintenance

Based on the factors for the selection of pipelines to be replaced as shown above, numeric values are assigned to each pipeline for different states under each selection criteria.

Taking account of the results of scored evaluation, it is recommended to replace the high risk pipeline and final selection of pipeline to be replaced is proposed as shown on Figure 4.4.6.

Diameter for the new replacing pipe will be discussed in the proceeding section together with future distribution network analysis.

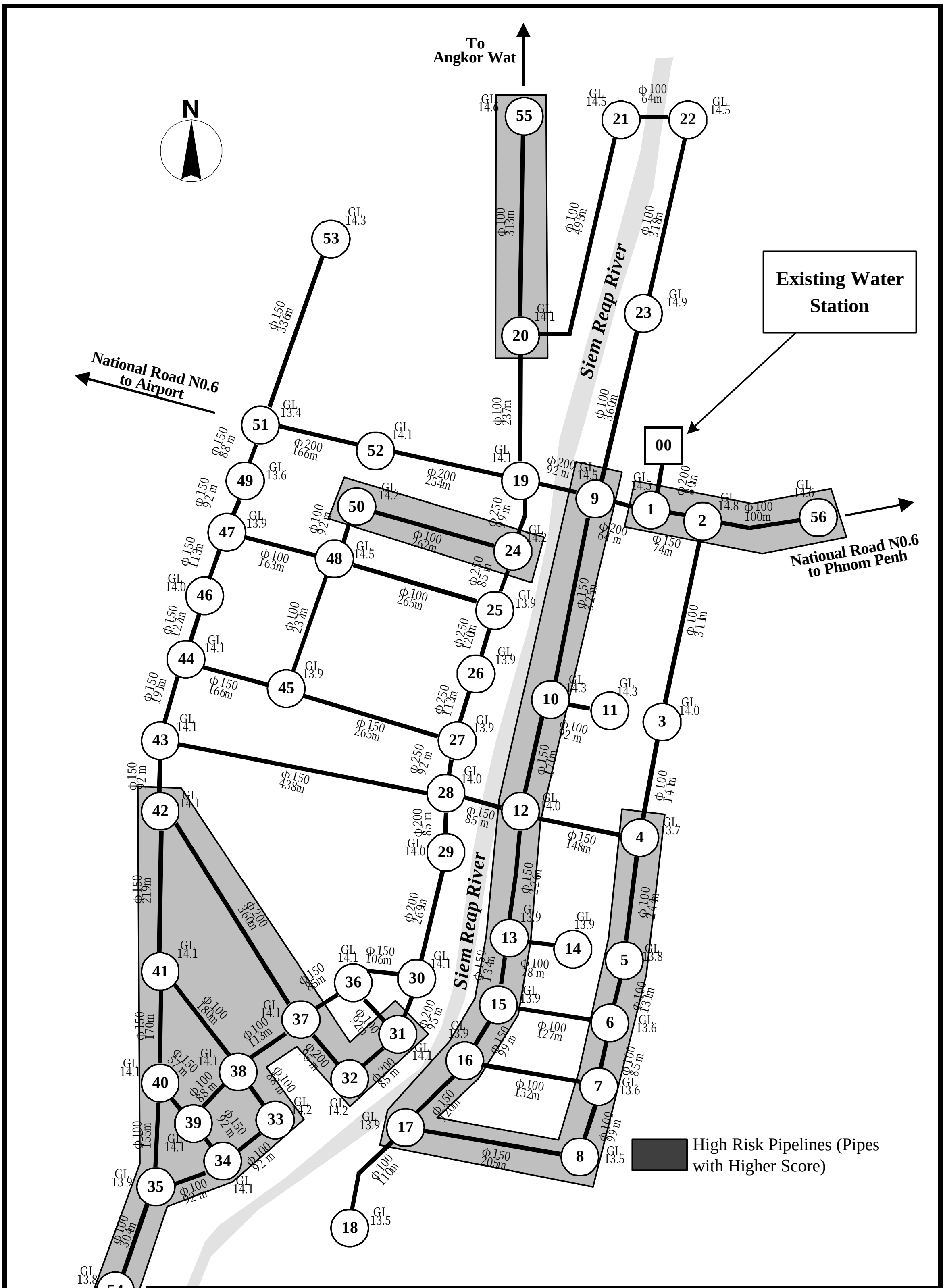

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Figure 4.46
High Risk Pipelines
(Proposed Pipelines to be Replaced)

High-risk pipelines are selected and these pipelines are recommended to be replaced. It should be noted that this does not mean the remaining pipelines are in good condition. Remaining pipelines were also installed from 1960s and they should also be replaced gradually after the replacement of the high-risk pipeline by the Siem Reap Waterworks using own funds or donor's assistance.