CHAPTER THREE

METHODS OF STUDY

Study objectives were accomplished with use of several different methods. This was necessitated due to the scope of the study and the nature of many of the variables investigated. Specific methodologies used in each phase of the research were outlined and described below:

3.1 Estimation of Construction Costs

3.1.1 The study was based on information and data collected from the Technical and Planning Subdivision of PWSD. The main sources of information and data were derived from the following items:

- Contracts
- Specifications and standards
- Construction details and lists
- Drawings or blue prints

The thirty water works projects with the collection works from surface sources were selected based on different designed capacity. Estimation of construction costs was conducted by Unit-Quantity technique. The procedures are briefly described as follows:

Quantity of all particular materials provided for construction of each structural components such as pumphouse, office, elevated tank etc. to completeness were directly taken-off from the specified drawings or blue prints and specifications. Materials also refers to the harden form works and scaffolds for placement of concrete wall or partition plastering and painting. Labour costs estimated were based on the quentity of works and suitable wage rate. Equipments for heavy construction if required were calculated on the basis of renting expenditure either per hour or per day.

The unit price of materials used, wage rates, equipment rents for construction of these selected studied projects are assumed to be available at Bangkok Metropolitan Area.

Summation of the above expenditure are the costs of each structural unit or else. They are shown and expressed in Baht. (U.S.$ 1.0 = ฿ 20.0)

The amount of different size and type of pipes are measured from drawings. The fittings, accessories, and apurtenances for the pipe systems are obtainable from direct measurement and also determined from total pipe length and the length of each piece of pipe at 4 or 6 metres long. For asbestos cement pipes, fittings and accessories, local unit prices are used for estimation. For gulvanized steel, cast iron pipes and all types of apurtenance, the unit prices depend on foreign imported condition. The reason for using foreign prices is because there was no domestical products of these materials really available at early construction periods.

The estimation of all types of supporters for pipes and earthworks are calculated in the same way.

The cost of machinery includes the expenditure for installation of these equipments ready for operations. The prices of equipments are foreign-rated while labour and other expenditure are locally rated.

Administration expenditure includes contractor's office expenses, tax, contingencies and profits were computed by means of approximation. Transportation expense were estimated based on distance from Bangkok to site and the price of gasoline. These were allowances for contractor's overheads and profits.

From the contracts, the actual lump sum of the successful bidded amounts of each project was known. Since the projects had been bidded in past different years from 1969 through 1975 and the monetary power of purchasing were not equal in each past year, so that cost index were available. These two types of index were not suitable for this case study because their measurements of monetary power change are not provided for construction conditions.

Adjusting the values by using escalation factors described in details in APPENDIX E, which was a method accepted by the Cabinet in 1974, was then introduced to relate past costs to the common present value using 1975 as a base year.

3.1.2 Components of construction items can be classified according to the function of the water works systems into intake, transmission, purification, distribution and other miscelleneous facilities.

By grouping these components within the plant, it was found that the construction works were divided into two parts. The first part was those directly related to the treatment and storage of water and were called the process part. The second part were those indirectly related or not concerning with the treatment or purification of water and were called the non-process part. Construction items outside the plant were transmission and distribution pipe-line systems. The included some components in intake facilities in process part which were designed to solve case problem such as reservoir, stabilized canal etc. and were called as intake special structures.

The reason why the construction works were grouped as described above was to find out the minimum requirement for these construction works in water-works system which might be omitted and not interrupt the system functioning. Moreover, estimation of total studied projects revealed the fact that summation of the costs for the process part not including intake special structures and the works inside the plants of the same designed capacity is approximately equal. The costs of construction works outside the plants expecially the pipe line systems were quite different, thus made the total construction costs of the same capacity project different too.

3.1.3 Costs of Lands were not included in the construction costs. Land required for installing the purification plant are approximately 5 - 15 Rai (8,000 - 24,000 square metre). Usually, another piece of land approximately 1 Rai (1,600 square metre) is required for intake pumping station. Costs of land vary very much from 2,000 ฿ to 150,000 ฿ per Rai depending on location situated. Sometimes, Provincial Water Supply Division pays nothing for required lands as they are belong toother goverment agencies. Land costs involved in calculation of depreciation and were not presented in this study.

3.2 Collection of Data on OMR Costs.

3.2.1 General survey was carried out to observed the operating procedures, the conditions of work, and the compositions of operating, maintenance and replacement (OMR) costs. the study was aimed at 44 water works with mature operating conditions. These water works are all with the collection works from surface sources.

Collection of data after above observing was quite complicated due to the regulation of government system. Each observed water works did not possess all concerned data required. In this phase of study, data were obtained from direct interview of superintendent of each water works, technical reports in each water works, and financial inventory from Finance Division. To avoid confusion, the fiscal year 1975 counting from October 1974 to September 1975 was selected as base time.

Raw data collected from each water works are as follows:

- Amount of produced water and sold water from year 1966 to 1975
- Amount of Customer connections from year 1966 to 1975
- Amount of each kind of sales and losses in year 1975
- Amount of consumed diesel gasoline for operating pumps in year 1975
- Amount of electric consumption in year 1975
- Work descriptions
- Number of staff, both officers and employees.
- Etc.

Raw data on financial status were collected from Financial Division, Public Works Departments as shown below:

- Unit cost of chemical used
- Unit cost for power and lighting electric tariff.
- Total expense of electric consumption in year 1975
- Total expense of diesel, benzene gasoline and lubrigants.
- Total expense of mainteance and miscellaneous
- Total salary of employees.
- Total fringe benefits of both officers and employees,
- **Etc.**

These data are monthly recorded in the inventory and technical reports. The sum over twelve months gives annual values.

3.2.2 Operating work can be classified into two parts, the production part and the service part. The production part is those associated with producing water while service part is those associated with serving customers. All expenditures in Article 3.2.1 are calculated and allocated to these two parts.

The average total unit cost of produced water are also calculated.

3.3 Statistical Interpretation

3.3.1 Arithmetic mean and standard deviation

Various components in construction and OMR costs are calculated in percentage of total values. Arithmetic mean and standard deviation were computed to measure the central tendency and dispersion of these treatments.

Arithmetic Mean,

$$\bar{X} = \frac{(x_1 + x_2 + x_3 + \dots x_n)}{N} = \frac{\sum X_i}{N} \qquad (3.1)$$

where X = independent variables

N = Numver of random samples

Variance,

$$S^2 = \frac{(X_i - \bar{X})^2}{N} \qquad \text{and}$$

standard deviation

$$S = \sqrt{\frac{(x_i - \bar{x})^2}{N}}$$

3.3.2 Value of constant 'K' and economies of scale factor.

Applying Chenery model to ralate cost and capacity of these systems.

$$C = KQ^{\alpha}$$

where C is either investment or OMR costs in 1,000 ฿

Q is either design capacity or average annual production in m^3/day

k is constant

α is economies of scale factor

There are 'n' sets of data such as (C_1,Q_1), (C_2,Q_2), (C_3,Q_3) ......, (C_n,Q_n) obtained from Article 3.1 and 3.2. Value of k and α can be determined by least square analysis from these n sets of data. Take the log transform for the above function.

$$\ln C = \ln k + \ln Q \tag{3.3}$$

Let $y = \ln C$

$b = \ln k$

$x = \ln Q$

So equation (3.3) becomes

$$y = \alpha x + b$$

$$\alpha = \frac{N \sum xy - \sum x . \sum y}{N \sum x^2 - \sum x . \sum x} \tag{3.4}$$

$$b = \frac{\sum x^2 . \sum y - \sum x . \sum xy}{N \sum x^2 - \sum x . \sum x} \tag{3.5}$$

Pearson product moment coefficient of correlation was applied to investigate the fitness of the derived equation.

$$R = \sqrt{1 - \frac{\sum (y - y_F)^2}{\sum (y - \bar{y})}} \tag{3.6}$$

where R = coefficient of correlation

y = log transform of data costs C

y_F = log transform of fitted cost C

$\bar{y} = \frac{\sum y_i}{N}$

A computer program was written for the determination of k and α as shown in Appendix D. The supplied input variables were C and Q obtained in Article 3.1 and 3.2 The procedure investigated seven relationships of

- cost of components in process part and design capacity
- cost of components in non process part and design capacity
- cost of components in both process and non process part or the treatment plant and design capacity
- cost of total construction investment and design capacity
- cost of production part and average annual production
- cost of service part and average annual production
- total unit cost of production and service part and average annual production.

3.4 Determination of Optimal Design Period.

In Article 3.3.2, the process investment and production OMR cost functions can be derived. These obtained results incorporated with equation (2.3) and (2.5), which were derived by Manne and Srinivisan, were applied to determine optimal time interval between the completion of constructing two successive plants or optimal design period.

For continous arithmetic rate of demand growth, installed capacity to meet water demand in x years ahead is

$$Q = xD_1$$

Applying Manne's equation to determine capital outlay to cover the costs of plant construction and costs of plant operating, maintenance and replacement. Thus,

$$C(x) = \frac{k_1(xD_1)^{\alpha_1}}{1-e^{-rx}} + \frac{k_2(xD_1)^{\alpha_2}}{1-e^{-rx}} \qquad (3.7)$$

The first term in equation (3.7) is investment costs in process part which are subject to economies of scale 'α_1' The second term is OMR costs in production part which are subject to economies of scale

To arrive at an optimal value of x, various values of x must be assumed and examined which value of x will give the minimum value of C(x). In equation (3.7), values of k_1, α_1, k_2 and α_2 are obtained annual incremental demand D_1 are appropriately assumed to be suitable for condition in thailand. Even values of D_1 do not effect the optimal design period, they are inserted in many values as, to observe the trial.

For geometric rate of demand growth, the assumed design capacity to meet water demand in x years is

$$Q_0 = D_0(e^{gx} - 1)$$

Then

$$C(X) = \frac{k_1\left\{D_0(e^{gx}-1)\right\}^{\alpha_1}}{1-e^{-(r-\alpha_1 g)x}} + \frac{k_2\left\{D_0(e^{gx}-1)\right\}^{\alpha_2}}{1-e^{-(r-\alpha_2 g)x}}$$

for $r > \alpha_1 g$ and $r > \alpha_2 g$ (3.8)

To solve for an optimal value of x, the technique used the same as mentioned in determining value of x in arithmetic rate type. A computer program was written to proceed such operation. The supplied input variables were:

k_1	constant in investment cost function for process part obtained from Article 3.3.2
α_1	economies of scale factor for investment costs in process part obtained from Article 3.3.2
k_2	constant in OMR costs function for production, part obtained from Article 3.3.2
α_2	economies of scale factor for production part obtained from Article 3.3.2
r	the annual rate of interest. The assumed values are 1.0,2.0,3.0.......,10.0,12.5,15.0,17.5,20.0 %
g	the geometric rate of growth. The assumed values are 1.0,1.5,2.0,.......,5.0,6.0,7.0,8.0 %
D_1	annual increase in demand (m^3/day/year) in arithmetic growth rate type. The assumed values are 1.0,2.0,3.0..... 10.0,20.0,.....100,150,200,250,300 m^3/day/year.
D_0	initial water demand (m^3/day). The assumed values are 100,200,300,......,1000,2000,3000,.......9000,10000,20000, 30000 m^3/day.
x	the optimal design period to be determined, in year.

The program data and results were shown in Appendix D.

3.5 Extrapolation of Water Demand

3.5.1 Water demand in this study refers to domestic demand. Average per capita demand is a function of time. Size of communities is also a function of time. So the per capita demand is related to size of communities. This assumed mathemetic function is

$$D = k P^n$$

Where D is water demand rate in lpcd.

P is size of communities or bulk population.

'k' and 'n' are estimated coefficient determined by regression analysis.

Per capita demand can be calculated from collected data in Article 3.2 and data collected from Department of Local Administration which were:

- population in each observed community from year 1966 to year 1975
- dwellings in each observed community from year 1966 to year 1975

$$D\ (\text{lpcd}) = \frac{1000(\text{Total annual sold water})}{365(\text{Served population})}$$

Served population = Number of connection X Average size of family

$$\text{Average size of family} = \frac{\text{Bulk population in served area}}{\text{Number of dwellings}}$$

The same computer program for determination of cost function was applied to formulate the assumed model. The first year demand D did not enter in the program since these values are not stabilized.

3.5.2 Amount of various types of loss were expressed in percentage of total sold water. Data were interpreted in arithmetic mean and standard deviation.

3.6 Construction of Water Rate Schedules

Constructed water rate for communities served by PWSD should be classified into two types.

3.6.1 Constant or uniform rate

For water works with design capacity less than 2,000 m^3/day, the unit OMR costs were quite large. Customers should pay for these OMR costs while government should subsidize a portion of the investment costs. The water works with design capacity less than 2,000 m^3/day are often constructed for small communities such as those in Sanitary Areas.

In this study, the average unit OMR costs of water works with design capacity less than 2,000 m^3/day was calculated by data shown in Article 3.2 and was used as water rate.

3.6.2 Incremental block and uniform rate.

For water works with design capacity over 2,000 m^3day, rates should be incremental block and uniform rate for residential

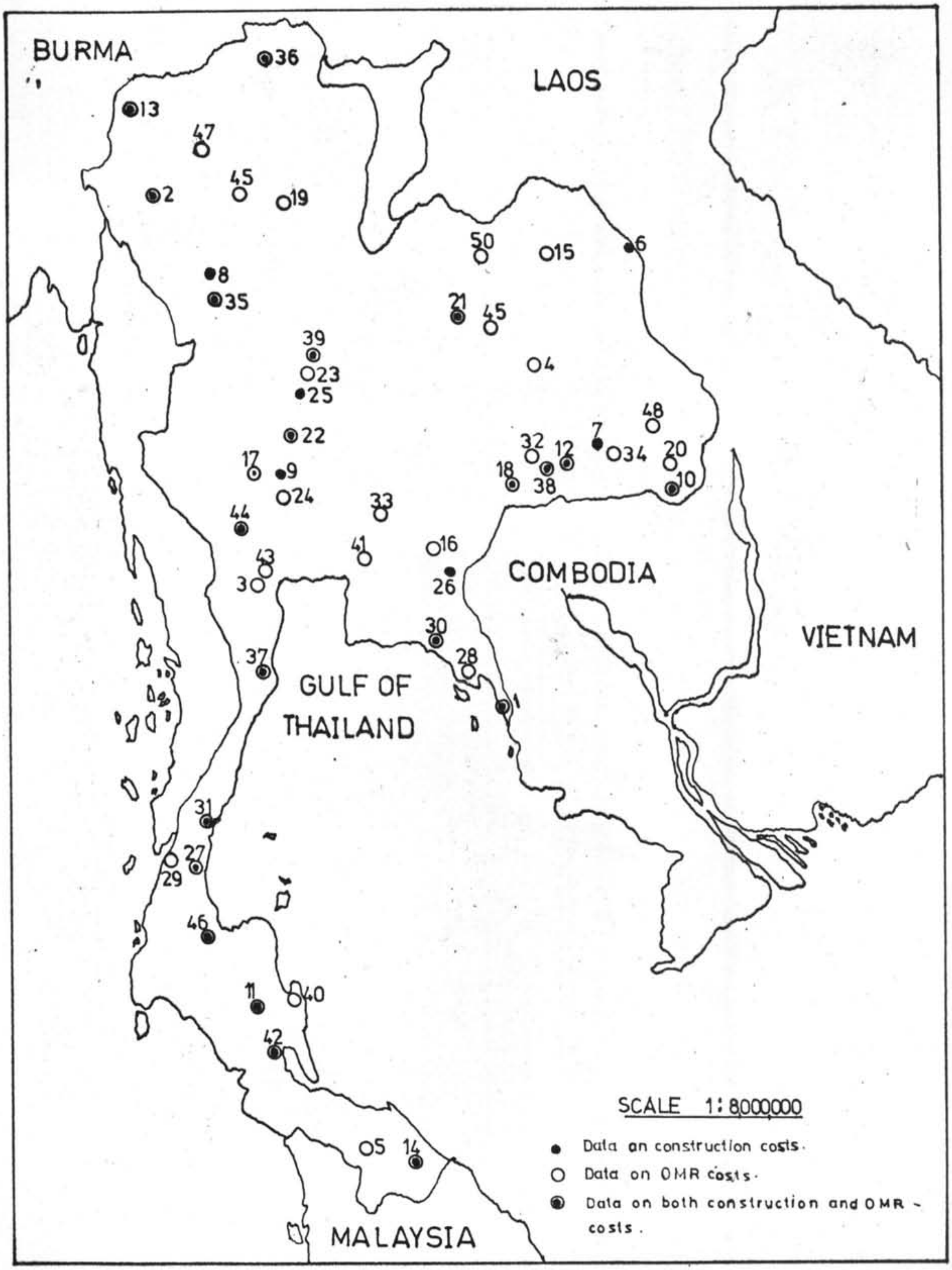

FIGURE 2 Location of studied water works.

customers and commercial and special customers classes respectively.

Rate base is the utility basis. It includes OMR expenses, depreciation and a return on the rate base. This required revenue was allocated into two customers classes as described below:

a. OMR expenses including compensation of losses was charged for every cubic metre of sold water.

b. depreciation was allocated to these two classed by per-centage of water use.

c. return on the rate base was burdensome on commercial and special customers.

In this study, constructed incremental block rates shown in Appendix F was for Chieng Rai water Works and was used as an example. Rates provided for National scale need much time in collecting data of each water works.

Selection of Water Works for Study

Collection of data was made through 50 water works provided for 55 communities in 35 provinces. Names and details of each water works were shown in Appendix A. The location of these water works were also shown in Figure 2.