CHAPTER TWO

LITERATURE REVIEW

2.1 The Economic and Engineering Evaluation in Central System Planning

U.S.P.H.S. (1970) suggested a wide guide for investment decisions which are planned by state or central agencies. It is also applied to water supply projects which should be based on the need, or in this case the water demand of the selected communities; an exploration through engineering technology and comparison of alternative ways of meeting the need ; and the calculation of the financial and economic consequences of the investment. This last aspect which is named by most text as cost and benefit analysis requires the determination and calculation of the cost and benefit of the proposed projects.

MARGLIN (1967) shows the role of investment costs and water supply data play in making investment decisions on location time, and scale. His concept of the benefit and cost analysis can be used to develop a ranking function for ordering the entire sets of alternative projects and recognized that planning over a number of years call for an analysis of project benefits and costs as a function of time. Briefly explained, his simple expression representing the total net benefits of any project as a function of time and project age is ;

$$B(z, z-t) = R(z).X(z, z-t) - M(z, z-t) - N(z).x(z, z-t) \qquad (2.1)$$

Where $B(z, z-t)$ = total net benefits of a project during year z

z = time measured in years from the present time

t = time of implementation measured in years from the present time

$z-t$ = age of project

$R(z)$ = prize per unit of output resulting from the implementation of a project

$X(z, z-t)$ = quantity of output in year z as a result of the implementation of a project in year t

$M(z, z-t)$ = fixed costs of operation in year z

$N(\ )$ = variable costs of operation per unit of output in year z

The above model applies to problems about the timing and amounts to be invested in several water resources projects during a fixed planning period.

In this chapter, Marglin's concept was used only as a fundamental assumption and extended for the study of three main constituents which implicitly influence in the benefit and cost analysis. These constituents are costs of the proposed projects water demand for the communities and the water rates.

2.2 Costs of Projects

There are some behaviours directly concerning the costs of projects economies of scale and there with an optimal time. In addition to these general behaviours, there are two other features which should be dominated only in water supply industry : cost components and costs of pipelines.

2.2.2 Economies of Scale Factor

CHENERY (1952) demonstrated in his model for predicting investment behaviour, that it might be economical to provide some excess capacity to take care of demand a number of years ahead. The optimal over-capacity is a function of the economies of scale, the discount rate, the planning period and the rate of increase in demand. His basic cost function equation is

$$f(V) = KV^{\alpha} \qquad (2.2)$$

Where $f(V)$ = undiscounted cost function for a single plant of size or capacity V

K = cost per unit size of a plant

α = economies of scale factor

AFFI (1969) also found that the economies of scale exists in water works practice. His study of over 300 water works in Illinois state shows that the total expenditure per unit gallon tended to decline down as the size of community served become larger. The result is much the same as was statistically carried out by SEIDEL ET AL (1950 and 1957) for publicly owned water works in the United States.

2.2.2 Optimal Time

MANNE (1967) presented several models concerning with time and scale of any investment. These models are developed for optimizing the size of successive plants in both single and multiple producing areas. The objective is to determine the capacity expansion policy which will meet an increasing demand at the minimum costs. Manne has developed his equation from chenery's model. In case of investment, cost function f(V) may be written as f(xD). Every x years over an infinite horizon, a plant is to be built. Each of these plant will have the identical undiscounted investment cost determined by f(xD). Thus, the sum of all discounted future investment costs looking from a point of regeneration, C(x) for the case of linearly increasing demand with no backlogs allows, can be determined from the following equation,

$$C(x) = \frac{K(xD)^{\alpha}}{1-e^{-rx}} \qquad (2.3)$$

Where $C(x)$ = present value of construction cost

D = annual increase in demand

x = time interval between the completion of constructing two successive plants.

e^{-rx} = present worth factor for costs incurred x years in the future.

K, α = are the same as in equation (2.2)

r = interest rate

Minimizing log C(x) is equivalent to minimizing C(x). Differentiating log C(x) with respect to x and equating the derivative to zero gives the optimal cycle time x^*, thus

$$\alpha = \frac{r\,x^*}{e^{rx^*}-1} \qquad (2.4)$$

In equation (2.4), it is observed that the four numerical parameters K, D, α, and r enter in equation (2.3) but the optimal value of cycle time x^* is independent of the cost constant K and of the annual increment in demand D. The only two parameters α and r do effect the optimal cycle time x^* for the determination of investment outlays.

SRINIVISAN (1967) applied Manne's model for a geometrically growing demand as shown following:-

$$C\ (x) = \frac{K\left\{E(x)\right\}^{\alpha}}{1-e^{-(r-\alpha g)x}} \quad \text{and} \quad r > \alpha g \qquad (2.5)$$

where $E(x) = D_o\ (e^{gx}-1)$

D_o = initial demand

g = instantaneous geometric growth of demand

Differentiating the log C(x) of Equation (2.5) with respect to x and equating the derivative to zero gives the optimal time interval of capacity or stage addition x^*. The optimal x^* is

$$\alpha\,g(e^{hx^*}-1) = h(1-e^{-gx^*})$$

$$\text{and} \qquad h = r-\alpha\,g > o \qquad (2.6)$$

In equation (2.6), the optimal cycle time x^* is also independent of the initial demand D_0 and cost constant K.

SCARATO (1969) applied Manne's model to time and size of urban water system expansion to meet a linearly growing demand. The economic impact of both the economies of scale in construction cost and of the interest rate of capital were analysed. The resulted model is the same as of Manne's.

LAURIA (1970) followed Manne's models to construct a mathematical model and mixed integer programming for centralized planning of water supply investment. His model required division of the planning horizon into discrete periods and is completed by constraint on construction fund and terminal conditions at the end of planning horizon.

BEENHAKKER (1975) also made examples on optimal time of various process industries. In one of his models, both investment and annual operating, maintenance and replacement costs are subject to each economies of scale factor. The mentioned model used for computing the present value of all costs is

$$C(x) = \frac{\rho K(xD)^{\alpha}}{1-e^{-rx}} + \left(\frac{xD}{W}\right)^{\alpha'} \int_0^{\infty} \frac{Wce^{-rt}}{1-e^{-rx}} \, dt \tag{2.7}$$

where $\rho = \frac{1}{1-e^{-rz^*}}$

$\dot{z}$ = expected life of the project due to

α' = economies of scale factor applying to annual OMR costs.

W = quantity of full-capacity output per year of the unit size of plant to which K applies.
c = aggregate of annual OMR cost per unit of output which are subject to economies of scale.

2.2.3 Cost components in Treatment Facilities

KOENIG (1967) reported the comparative cost engineering audits obtained from 30 water treatment plants in the United States. This comprehensive study on the cost of water treatment in existence gave much attention an details of annual operating and maintenance costs which are affected by plant capacity and annual average use rates. The contribution of cost components for two typical plant size 0.5 mgd and 8 mgd operated at use rates of 0.5 and 1.0 is that the capital amortized over 30 years at a discount rate of 4%, man power, energy, chemicals, heating, maintenance and repair contributes about 40-55%, 22%, 10-13%, 6%, and for the last three items with each 2% of the total treatment costs. He also regressionally analysed unit investment cost against raw water design capability. The equation shows that the total investment costs varies with the 0.67 power of the capability which shows nearly the same result as those derived by ORLOB and LINDORF (1958) by the ILLINOIS STATE WTR. SURVEY(1968), and by LEEDS et al (1970).

From Koenig's statistical record, HINOMOTO (1971) firmly stated that economies of scale exists in water treatment plants and found that each cost components can be related to some economies of scale factors. He derived the equation for estimating the total cost of water treatment which is shown together with others' works in Table 2.

TABLE 2. Derived equations of cost function

Process	Equations	Reference	Symbols
Water treatment by flocculation, sedimentation, rapid sand filtration and chlorination	$C_c=257\ Q_n^{0.67}$ $C_o=68.4\ Q_a^{-0.41}$	Orlob and Lindorf (1958)	C_c = total capital cost of a complete water treatment facility in thousand dollars C_o = cost of operation and maintermance in dollar per million gallons. Q_n = design capacity in mgd to be reached in n years Q_a = average daily flow in mgd.

TABLE 2 (continued)

Process	Equations	Reference	Symbols
Water treatment by coagulation, sedimentation and rapid sand filtration	$C = 30.7\ Q_d^{-0.323}$	Koenig (1967)	C = unit investment in ¢/gpd Q_d = raw water design capability in mgd.
Water treatment	$C_c=383.8\ Q_n^{0.65}$	Illinois State Wtr. Survey (1968)	C_c, Q_n are the same as above
Complete treatment without softening	$C_c=580\ Q_n^{0.70}$ $C_o=32.6\ Q_t^{0.59}$	Leeds and Jewett (1970)	C_c, Q_n are the same as above Q_t = Quantity of water treated M = Chemical cost approximated \$5/100ppm hardness removed per acre-foot treated
Softening	$C_c=250\ Q_n^{0.825}$ $C_{o-1}=37.5Q_t^{0.59}$ + M		

TABLE 2 (continued)

Process	Equations	Reference	Symbols
Water treatment by coagulation, sedimentation and rapid sand filtration	$C = D+E+F+G+H+I+J$ $D = 819SQ_d^{0.675}$ $E = 12.0(UQ_d^{0.764})$ $F = 27.8(UQ_d^{0.718})$ $G = 3.07\ Q_d^{0.481}$ $H = 27.3Q_d^{0.687}$ $I = U^{0.5}(4.05Q_d^{0.579})$ $J = 1.02Q_d^{0.93}$	Hinomoto (1971)	C = total daily cost in dollars per day Q_d is the same as Koenig's U = daily use rate S = annual amortization factor D = capital investment cost E = Chemical costs F = Pumping energy cost G = Heating energy cost H = Manpower cost I = Maintenance and repair cost J = Miscellaneous cost

ATHIKOMRUNGSARIT (1971) carried out the impact on cost effectiveness of providing potable water in Thai rural communities. Unit construction and annual operating costs in details obtained from 88 plants of various capacities ranging from 10 to 50 m^3/hr and of three types of treatment; namely, conventioned rapid sand filtration; aeration, sedimentation, slow sand filtration; and chlorination of deep well water only were hypothetically computed ranging about 0.61 - 2.24 and 0.37 - 0.98 ฿/m^3 respectively.

2.2.4 Costs of pipe lines

Apart from investment and annual operating costs of treatment plants reviewed in Article 2.2.3, there were costs of pipelines considered to be of great importance too.

LINAWEAVER and CLARK (1964) performed a regression analysis of the cost of fifty oil, gas and water pipelines and reported that the cost per linear foot of a pipe may be approximated by

$$C_{pipe} = 0.358\, d^{1.29} \qquad (2.8)$$

where the unit of diameter, d, is in inches.

The cost expressed by this equation accounts for the costs of land or right of way, pipe line construction and maintenance.

LIDDLE and HODGSON (1967) presented an exploratory study of transport of chemicals by pipeline and found that laying larger size of pipelines result in lower the unit investment costs dollar per inch of pipe diameter per mile of pipe length due to progressive construction techniques.

PAINE and WHITE (1969) presented the characteristics of the cost of a simple pumping main. By chosing appropriate unit costs under some input data of demand, distance, pipe friction, and discount rate, he derived many cost functions for the economic comparison of pumping mains of similar design.

Annual costs of operation for transporting water were studied by Koenig (1967) in terms of energy costs as mentioned in previous article.

2.3 Demand for water

2.3.1 General concepts

Demand is one important constraint which limits production rate and plant capacity. In economics, demand of any product or commodity is a function of its' price. The conventional procedure for the forecast of water requirement is to project poputation on the basis of past trends and to predict the corresponding per capita demand expected. The water use is the product of these two factors. Implicity, the conventional method assumes that the demand for water in inelastic or is not affected by price of water. The criticisms of neglect of the price demand relationship in demand projections were discussed by Seidel et al (1957), Flack et al (1966), Howe and Linaweaver (1967), Hirshleifer et al (1963) and Clark (1976) after statistically investigating various variables which some will be described in the following paragraphs. It should be noted that their data are based on the average price and consumption per capita over the entire water service ares.

U.S. AID (1969) classified the basic factors which can be related to community water demand into six categories: social conditions, economic conditions, natural environmental conditions quality of water service, quality of the water supplied, and costs of water. Models used to express water demand are either univariate or multivariate demand function.

HOWE and LINAWEAVER (1967) worked with multiple linear and logarithmic demand models incorporating several independent variables for both average domestic demand and sprinkling demand. Factors which showed much effect on domestic demand were market value of the dwelling unit, number of persons per dwelling unit, age of the dwelling unit, average water pressure, and sum of water commodity charges and sewer charges which varied with water use. Their study covered flat rates too and showed that price play no role in determining demands.

FLACK and HANKE (1968) showed a hypothetical example depicting metering effects. They carried out the study at Boulder, Colorado resulting that complete metering dropped demand about forty per cent indicating that capital expenditures could likewise be reduced until a future date.

LLOYD (1960) indicated that the use of meters could eliminate waste and misuse of water. An accurate accounting of the water used by each customer and equitable distribution of the cost of supplying water made possible an accurate determination of the water used and lost. Establishing a good and equitable rate structure reduced the cost of water production and delivery to the customers. On a payment of the flat rate, a consumer was free to use as much water as he desired without incurring additional costs. The conclusion was that water use in metered areas is considerably less than that in flat rate areas.

CSALLANY (1965) studied the relationship between water demand and population showing that metered water demand in gallons per capita per day in the United States could be estimated by the relation 34 log (P/10) where P is actual population. It was shown that metered water demand was 30 - 35 gpcd (113.6 - 132.5 lpcd). If the service connections were not metered the water demand was about 75 gpcd (276 lpcd)

GEYER ET AL (1967) showed seasonal effects on daily water demand for a metered, residential area. Average summer use exceeded average winter use by a factor of three. Daily summer demand was as high as five times the average daily winter use.

TABLE 3 Water consumption concluded from the studies.

Descriptions	Meter areas gpd(lpd)/dwelling unit	Flat rate areas gpd(lpd)/dwelling unit
Household	247 (935)	236 (893)
Sprinkling	186 (704)	420 (1590)
Leakage	25 (95)	36 (136)
Total	458 (1734)	692 (2619)
Maximum day	979 (3706)	2354 (8910)
Peak hour	2481 (9391)	5170 (19568)

2.3.2 Investigated Demand in Thai Communities

RUTHERFORD (1968) studied water usage in Northeastern areas for 5 villages which used shallow wells without house connections revealing that average daily demand was 27.3 lped. In villages where raw water sources were far away, people were using water at 35 - 40 lpcd, but in those villages where raw water sources were close, the consumption not including bathing was 20 - 25 lpcd.

TAMTARANON (1969) detected water demand in Nakhon Chieng Mai Province served by two - 24 hour operated treatment plants of 250 m^3/hr. He concluded the result that average daily domestic, maximum day, and maximum hour consumption should be raised to 144,200 and 300 lpcd respectively for the purpose of designing the expanded system in this province. He also presented those figures of demand for various types of users in that service area.

SHOUVANAVIRAKUL (1970) studied water consumption in 14 rural communities of Northeastern Thailand to determine water needs and to delineate the factors that affect water use. For 13 of these communities, average daily water consumption ranged from 10 to 90 lpcd. Another last village with water distributed through house connections 24 hours per day, water usage ranged from 115 to 160 lpcd. Water consumption was significantly influenced by the season of year, limited hours of availability of water through the distribution system, type of water service connection, and price of water for metered house connections only. Maximum daily and maximum hourly demands were found to be 1.5 and 4 times the average daily water consumption respectively.

2.4 Water Rates

One fundamental consideration for investment decision of any water supply project is how to obtain the revenues in an amount that will suffice to provide adequate service and assure the maintenance, development, and perpetuation of the proposed project. The revenues are generated through water rates. Many proposals are offered for rational water policies usually justifying high rates for sufficient revenues and for better service. On the other hand, politicians are concerned with low rates for economic growth.

Economists encourage marginal cost pricing policy for economic efficiency. Thus, it is essential to determine appropriate water rate regarding to above consideration.

2.4.1 Types of water rates

Parts of GYSI (1971) study, also in some other literatures and texts, shows that there are various types of existing water rates which are discussed as follows:

2.4.1.1 Flat rate - the most usual method when service connections are unmetered. This type of rate is applicable when there is an adequate amount of cheap water supply. A fixed amount of charge per month is paid regardless of the amount of water consumed. Flat rate is uneconomical for they encourage the wasting of water and do not provide and equitable basis for charges to widely different customers.

2.4.1.2 Unmetered, variable rate - the alternative to the flat rate when service connections are unmetered. A variable water use charge is applied, based on considerations other than actual flow measurement, such as property status, area of property, front footage, area of house or building on property, number of fixtures, and size of service connection.

2.4.1.3 Metered, with constant rate. In this type of rate, unit rate is charged for all consumers. This type of rate structure is appreciated by economists as it assumes equimarginal value in use to all consumers. The rate neither rewards to high users nor penalize them.

2.4.1.4 Metered, with declining block rate - this is the type of rate structure widely used in the United States. The declining block schedule is based on the dubious assumption of declining costs associated with increased consumption. The reason for such type of rate is that amount of small customers is proportionally more to serve than of large customers so that these small customers should pay proportionally more. Recent literatures discussed by Hanke (1975) and Goolsby (1975) shows several significant defects of this type of rate structure impose on investment decision.

2.4.1.5 Metered with incremental block rate. The rationale of this social rate structure is one of satisfying the basic water needs of low income groups at a very low (normally below cost) price, while also providing some motivation to limit water use such as reducing lawn sprinkling and fixing leaks. By this method, the large consumers are, in fact, subsidizing the small consumers. This method can in some cases increase the total revenue to the water works.

Minimum charge is also included in nearby all types of rates for metered water service to cover the cost of the utility's readiness to serve.

2.4.2 Declining Block Rate Schedules

AWWA COMMITTEE (1972) revised the widely used method of determining water rate which is the declining block type.

Determination of rate schedule by this manual which could be adaptable to other types of rate is presented in five section as follows:

Revenue Requirements Two approaches are discussed to determine the total amount of revenue required. They are the utility basis and cash basis

The utility basis determines a rate base, or the value of the property upon which the utility is entitled to earn a return, and the fixing of a fair rate of return on the rate base. Thus, total revenue requirement would include operation and maintenance expense taxes, depreciation, and a return on the rate base.

The cash basis is used when the water utilities are not operated for a profit, but attempt only to cover total operation costs and to provide for investment in plant facilities. The items in cash basis are separated into basic and optional classification. The basic items are operation and maintenance expenses; debt service requirements; plant replacement; and normal plant extensions and improvements. The optional items are taxes; major plant improvements; and some contributions.

Allocation of Costs of Service to Cost Functions. The distribution of costs of service are considered using either the commodity demand and the base extra capacity methods. In the commodity - demand method costs of service are separated into three primary cost functions - demand costs, commodity costs and customer costs. Demand costs are associated with providing facilities to meet the peak rates of demands. Commodity costs are those which tend to vary with the quantity of water produced. Customer costs are those associated with serving customers irrespective of the amount of water used or maximum demand.

In the base-extra capacity method, all costs are separated into three components : base, extra capacity, and customer costs. Base costs are commodity costs plus those operating and capital costs associated with service to customers under average load conditions. Extra-capacity costs are those associated with meeting rate - of use requirements in excess of average and include capital and operating charges for additional plant and system capacity beyond that required for average rate of use. Customer costs are the same as in the commodity - demand method.

Allocation of Costs to Customer Classes. There are typically three principal customer classes: residential, commercial, and industrial. The costs by either commodity-demand or base-extra capacity method are distributed through these customer classes regarding to factors which provide a measure of customer class cost as annual water use and maximum demand characteristics, number of customers, bill rendered or meters used and serviced.

Other Considerations in Distributing Costs. Tax payers, normal and special users should be specially considered in allocation of costs due to particular water demand characteristics such as fire protection, law irrigation, air conditioning and refrigeration.

Development and Design of Rate Schedules. In designing water rates, recognition of costs associated with four basic levels of customer usage provides a basis for the selection of usage block and the development of rates for respective blocks. Initial block may be designed to recover customer costs and costs associated with use and capacity requirements of the smallest users. Three subsequent rate blocks are designed to recover costs associated with use and capacity requirements of residential and small commercial customers, large commercial and small industrial customers and large industrial customers. It should also be recognized that rate schedules in final analysis may be adjusted to recognize past practices, legal requirements, or other local circumstances.

2.4.3 Proposed Rate Schedules in Thailand

In Bangkok Metropolitan areas, Camp Dresser & Mckee (1968) suggested uniform or constant rate in a master plan submitted to MWWA. However, to cover the large capital expenditure required for construction in first and second stages, MWWA has suggested the water rate schedules which was approved by National Executive

Council as follows:

Water Consumption (cubic metre/month)	Rate (฿/m^3)
0 - 6	Free
7 - 12	0.50
13 - 25	1.00
26 - 50	1.50
51 - 200	2.00
Over 200	2.50

KRÜGER (1968) submitted feasibility study for expansion of water works in Chonburi, Lampang, Surathani, Tapanhin and Nakhon Rajsima to PWWD. The reports suggested uniform or constant rate by applying the following empirical formula :

$$b = \frac{e}{0.9} + \frac{2L.t}{(2Q+R)100 \times 0.9} \qquad (2.9)$$

where Q = actual water production at beginning

R = addition or increased production

L = Invested capital

e = Direct production cost

t = Indirect production cost

b = uniform or constant rate

Krüger assumed that water user will be raised to 90 % of the population in the served area. Hence the calculated rates required to cover the capital expenditure and annual operating cost are about 4.16, 3.97, and 3.11 in first, second and third stages respectively.

OTCA (1973) submitted feasibility study for expansion of water works in Chieng Mai Province. Uniform rate of approximate 3.50 - 4.0 Baht per cubic metre is calculated by using break even analysis of water sale revenues and cash flow of amortized fund with 2.75 per cent interest rate including the annual operating costs.

WRPS (1975) submitted feasibility study for expansion of water works in Pattaya seaside region. WRPS gave two assumptions for determining rate schedules. First, if water supply is a fundamental of infrastructure in developing country, rate should be derived from only operating costs. Second, if water supply is a kind of business being invested, rate should be derived from both capital being amortized under accepted interest rate and annual operating cost. Water Boards also classified the comsumers into two classes as residential and commecial ones. Minimum uniform rates of two and five Baht per cubic meter are charged for residential and commercial consumers respectively.