10.1.2 Costing data

The costs involved in constructing and operating a waste water treatment plant can be broadly divided into two categories: (1) investment costs and (2) operating expenses. The investment costs are all costs required for the construction of the waste water treatment plant and include items such as:

- Preliminary studies;
- Acquisition of a construction site and preparation for building;
- Project costs such as design, engineering and legal affairs: e.g. permit applications and environmental impact assessments;
- Civil work, equipment & instrumentation costs, including process control systems;
- Construction and installation;
- Commissioning (i.e. testing and accepting the installation) and start-up costs.

The operational costs are all costs incurred to maintain and operate the waste water treatment plant and include items such as:

- Personnel;
- Maintenance costs;
- Operational costs: chemicals, utilities, lab supplies, office supplies etc.;
- Aeration costs (electricity);
- Sludge disposal costs.

In this chapter the focus will be on the optimisation of the (annualised) construction and operational costs, as these are the costs that can be influenced by the optimised design of the waste water treatment plant.

10.1.2.1 Investment costs

Construction costs are the main item in total investment costs, although the contribution of the other cost items is significant. In Table 10.1 a typical example is given of a breakdown of investment costs for a waste water treatment plant. In the example the cost of site acquisition and infrastructure works (items 1.1 and 1.2) have not been included as these are very site-specific.

For municipal waste water treatment plants in particular, the cost of constructing a sewer system, pumping stations and pressure lines can be very high and will usually be higher than the cost of constructing the waste water treatment plant itself. These costs are less important for industrial waste water treatment plants, which are often located on the factory site and near the source of the waste water.

The construction costs of the main treatment units of the waste water treatment plant covered in this book (i.e. item 2.1 to 2.3 in Table 10.1) typically comprise between 50 - 70% of the total investment costs, depending on the size of the waste water treatment plant.

In order to estimate the construction costs in the early stages of the waste water treatment plant design, unit volume costs are attributed to the different main treatment units. Similarly, unit costs per installed kW are assigned to aeration equipment and equipment for energy generation. These costs cover the expenditure of raw material and equipment, all civil and mechanical construction work and the installation of local electrical equipment and instrumentation. In the case of diffused aeration, apart from the blower package this includes the costs of the aeration elements, connecting pipelines, valves and instrumentation.

Table 10.1 Typical division of investment cost items as proportion of total investment

Main cost item	Proportion of investment (excl. 1.1 and 1.2)	Description
1 Preparation		
1.1 Site acquisition	not included: location dependent	Acquisition of building plot, brokers, notaries, taxes
1.2 Infrastructure	not included: location dependent	Access roads, sewer lines and effluent discharge pipelines, power supply
1.3 Site preparation	0.5 - 2%	Demolishing, ground work, rerouting pipes & cables, roads
2 Construction		
2.1 Civil	23 - 29%	Construction of tanks, buildings, foundations etc.
2.2 Mechanical	21 - 27%	Equipment costs incl. installation, local piping
2.3 E&I	10 - 16%	Local instrumentation and electro-technical equipment
2.4 Piping	2 - 5%	Interconnecting piping, utilities, sewers, including insulation and tracing
2.4 Central PC/E&I	2 - 5%	Central process control incl. software, motor cabinet (MCC), substation, frequency converters, cable work
2.5 Contingency	10 - 20%	Allowance for unforeseen expenses
3. Start-up	1 - 3%	
3.1 Equipment	included in 3	Maintenance and lab. equipment, computers etc.
3.2 Start-up supplies/spares	included in 3	Chemicals, first fills (activated carbon, filter material). Fittings, cables, etc.
3.3 Personnel	included in 3	Hiring & training employees
4. Additional	10 - 20%	
4.1 Initial studies	included in 4	Feasibility study, system selection, geotechnical survey
4.2 Design and engineering	included in 4	Basic & detailed design and engineering, requisitions and tender process, procurement
4.3 Project management	included in 4	Planning and budget control
4.4 Construction management	included in 4	Site supervision, testing and commissioning
4.5 Miscellaneous	included in 4	Permits, taxes, insurance

Table 10.2 Value ranges of costing parameters (based on the price level in 2006) for different WWTP sizes

Parameter/Capacity	25,000 P.E.	50,000 P.E.	100,000 P.E.	200,000 P.E.
Cost per unit measure of volume (US$.m^{-3}):				
C_{ps} - primary settler	600 - 900	400 - 650	300 - 450	200 - 350
C_u - UASB	600 - 1000	500 - 700	350 - 500	250 - 400
C_r - aeration tank	220 - 300	180 - 250	150 - 200	120 - 170
C_d - final settler	350 - 550	300 - 400	250 - 330	200 - 260
C_{th} - sludge thickener	700 - 1000	500 - 800	300 - 500	250 - 400
C_{di} - anaerobic digester	600 - 1000	450 - 700	300 - 400	250 - 350
Cost of installed kW (US$.kW^{-1}):				
C_{ae} - surface aeration	4500 - 7000	4000 - 5200	3200 - 4000	2800 - 3500
C_{ae} - diffused aeration	6000 - 9500	5500 - 8000	5000 - 7200	4000 - 6000
C_{gen} - power generation	2500 - 5000	1700 - 3500	1500 - 2500	1000 - 2000

As can be observed in Table 10.2, costs per unit volume and per kW installed increase for smaller waste water treatment capacities. This is one of the reasons why, for instance in the Netherlands, the trend is to construct very large waste water treatment plants, (> 1.0 million P.E.), replacing several smaller installations. However, the reduction in construction costs for the waste water treatment plant has to be balanced with the increase in construction costs for sewerage supply and effluent discharge network. The upper range values in Table 10.2 correspond to a well-equipped modern municipal WWTP in developed countries. For instance the construction of the basins will be mainly in concrete while pumping stations, control rooms and equipment are all located in concrete buildings. Furthermore the level of automation will be quite high. The lower end corresponds to industrial installations and municipal installations in developing countries, where equipment is often skid mounted and located outside under a shelter.

In addition to the main treatment units discussed in this book, a typical (municipal) waste water treatment plant will contain the following additional treatment units that contribute significantly to the total construction costs:

(1) Influent lifting station where all sewage streams are received and lifted to a hydraulic level that permits the flow of the waste water through the water line (pre-treatment, activated sludge treatment and clarification) by gravitation;
(2) Screening: for the removal of large debris, such as leaves, plastic, rags etc;
(3) Sand trap: removes sand, gravel and potentially also oil, fat and grease;
(4) Off-gas treatment: e.g. lava filters that treat contaminated air from covered units such as primary settling tanks, screening operations and the sand trap;
(5) Control and maintenance buildings, laboratory and storage facilities, including required heating, ventilation and air conditioning (HVAC);
(6) Chemical dosing units, e.g. metal salts, polyelectrolyte including storage facilities;
(7) Sludge dewatering: filter presses, decanter centrifuges or sludge drying beds, sludge buffer/dewatered sludge storage.

In the case of industrial treatment, the waste water is often delivered in a single pressure line or received in a buffer tank. An influent lifting station, screening units and a sand trap are often not required. However, other units may be installed such as oil separators, dissolved air flotation (DAF) units and polishing steps such as advanced oxidation, sand filtration and activated carbon adsorption.

For municipal waste water treatment or industrial installations with a similar configuration, the construction cost of the additional units listed above (i.e. item 1 to 7) is dependent on the treatment capacity and ranges between 20% (large capacity) and 35% (small capacity) of the total construction costs. Thus once the construction cost of the main treatment units are estimated, the total construction costs can be calculated by multiplication with multiplier f_{ac}. Values of f_{ac} as function of the WWTP size are listed in Table 10.3.

Finally, to obtain the total investment costs, the remaining cost items listed in Table 10.1 will have to be accounted for: i.e. items 1.3, 2.4, 2.5, 3.1 to 3.3 and 4.1 to 4.5. A rough estimate of these costs is between 50 (large capacity) and 100% (small capacity) of the total construction costs. To include these cost items, a second multiplier f_i is introduced. Typical value ranges are shown in Table 10.3.

Table 10.3 Values of multipliers used to calculate the total investment costs of a waste water treatment plant from the construction costs of the main treatment units for different treatment capacities

Capacity	25,000 P.E.	50,000 P.E.	100,000 P.E.	200,000 P.E.
f_{ac} [(1)]	1.4 - 1.5	1.35 - 1.45	1.3 - 1.4	1.25 - 1.35
f_i	1.6 - 1.9	1.5 - 1.8	1.5 - 1.7	1.4 - 1.6

Note: [(1)] This factor only applies to "typical" municipal waste water treatment plants with a configuration similar to that as discussed earlier in this section, i.e. equipped with item (1) to (7)

A final note about the data presented in Tables 10.2 and 10.3: as local conditions and prices change from location to location, the accuracy of any cost estimate based on these figures can be no higher than ± 40 to 50% at most. To obtain a more accurate estimate, a proper design and engineering study will be required, including priced vendor quotations for the main equipment.

On the other hand, the cost factors introduced in this section can be very useful in the optimised design procedure as they allow evaluation and comparison of different system configurations on a different criterium than total treatment volume alone. As can be observed in Table 10.2, the main treatment units differ considerably in cost per m^3 volume.

10.1.2.2 Operational costs

Operational costs are all costs incurred to maintain and operate the waste water treatment plant and include items such as:

- Personnel and maintenance;
- Operational costs (chemicals, utilities, lab supplies, office supplies etc);
- Insurance;
- Aeration costs (electricity) and heating costs (for the anaerobic digester);
- Costs for sludge disposal;
- Effluent discharge costs (per P.E.).

The value of the first three items depends for a large part on the efficiency of the operating company, but for the purpose of cost estimation is taken as a percentage of the total investment costs. Often different maintenance percentages are used for civil works and mechanical/instrumentation equipment, as the latter generally require more maintenance. Insurance costs are also taken as a percentage of total investment costs. For the aeration costs, the price per kWh is required. This price not only covers the production costs of electricity, but also that of transport, taxes and connection. For heating costs the price of the appropriate fuel can be used (natural gas, gas oil). Depending on the process configuration, sufficient heat may be generated from the digested sludge to cover the heating requirements.

The costs of sludge disposal may vary considerably, depending on the possibilities of reuse and the legal requirements for sludge disposal. Often the dewatered sludge has a dry solids content of 20 - 30 % wt., although this can be much higher (up to 90%) when drying beds are applied. When the sludge can be disposed at a landfill, cost per ton dry sludge can be very low, e.g. between 80 - 100 US$ ton dry sludge. However, if this is not allowed, then the dewatered sludge will have to be treated. Several methods are available: by far the most common ones are incineration, composting or drying followed by reuse as a raw material in for instance the cement industry. In this case the cost of disposal may easily be as high as 300 US$.ton TSS^{-1}. Transport costs will have to be added to this amount.

Table 10.4 Typical value ranges for the cost items included in the operational costs

Operational cost item:	Symbol	Range	UoM
Personnel	$p \cdot I$ (1)	2 - 5%	US$.year^{-1}
Operation	$o \cdot I$ (1)	0.5 - 1.5%	US$.year^{-1}
Maintenance - civil - mechanical/E&I	$m \cdot I$ (1)	0.5 - 1.0 % 1 - 2.5 %	US$.year^{-1}
Insurance	$n \cdot I$ (1)	0.2 - 0.4 %	US$.year^{-1}
Electrical energy	C_{el}	0.05 - 0.20	US$.kWh^{-1}
Heating energy	C_h	0.2 - 0.5	US$.m^3 gas/…/
Sludge transport & disposal	C_{sd}	80 - 500	US$.t^{-1} TSS
Discharge levies	C_{dl}	20 - 70	US$.PE^{-1}

Note (1) I = total investment costs of the system

Finally, if applicable, levies might have to be paid for the residual organic- and nutrient load discharged with the effluent to municipal sewer systems. This does not apply to municipal waste water treatment plants or to industrial treatment plants discharging directly to surface water. Table 10.4 shows typical ranges for the different operational costs items.

10.1.2.3 Annualised costs

A fundamental aspect in the design optimisation is the calculation of the total annual treatment costs, including both investment costs and operational costs. To be able to compare the two cost types, it will be necessary to annualise the investment costs over the expected lifetime of the treatment plant, transforming them into net present value (financing costs). To transform the investment costs into net present value the following formula can be applied (De Faro, 1986):

$$R = I/a_{i,n} \text{ with } a_{i,n} = [(1+i)^n-1]/[i\cdot(1+i)^n] \quad (10.1)$$

Where:

I = total investment costs (investment), in present value
R = annual financing costs during the expected economic lifetime of the system
i = interest rate (annual)
n = economic lifetime of the treatment plant

Often a distinction is made between the economic lifetime of the civil part of the WWTP and that of the mechanical and E&I part: for instance 30 years for civil and 15 to 20 years for mechanical and E&I. This requires the total investment costs I to be divided into different fractions. A typical proportion of costs is about 35 - 45% for civil, 30 - 45% for mechanical and 15 - 25% for E&I.

Equation (10.1) is a simplified expression in which it is assumed that the treatment plant will have no residual value after the expected economic lifetime, inflation is disregarded and the annual terms are equal until the end of the economic lifetime. However, the expression is adequate enough for an indicative analysis of the generated design. The calculated annual financing costs are added to the expected operational costs and the total costs can be used to compare design alternatives in various formats such as (1) annual costs, (2) costs per unit volume of treated waste water and (3) cost per people equivalent.