Estimating Costs for Treatment Plant Construction

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Preliminary cost estimates can be used to compare the economics of various treatment processes or the costs of major project components. Such estimates do not, however, represent the actual construction and operation and maintenance costs of the project. Actual project costs are site-specific, cannot be generalized, and must be developed for individual circumstances.

Estimating costs for any project is a broad and complex task. It requires experience, engineering judgment, hard work, and to some extent, guesses based on familiarity with the project and the area.

Reliable construction and operation and maintenance (O&M) cost data on any water treatment project are essential for planning, design, and construction. Estimating costs is required during project planning as well as during design and construction. Different degrees of accuracy are needed for each phase.

During the planning phase, preliminary cost estimates are developed for major project components and often for alternative process trains. These cost estimates are used to compare and evaluate process alternatives. Therefore, they must be accurate enough so that sound decisions concerning alternative selections can be made.[1] These estimates are also used for arranging project

TABLE 1
Generalized construction and O&M cost equations and cost components

Process	Construction Cost								
	Equation	Component Cost—*percent*							
		A†	B	C	D	E	F	G	H
Chlorine storage and feed	CC‡ = $680.75\,x^{0.763} + 11{,}010$								
Cylinder storage			47			6	4	5	38
On-site storage tank with rail delivery	CC = $0.329\,x^{1.515} + 178{,}310$		80		2	8	3	5	2
Direct feed from rail car	CC = $374{,}564\,x^{-0.149}\,e^{0.000173x}$ x = chlorine feed capacity—*kg/d*		82			6	4	6	2
Ozone generation	CC = $18{,}631.2\,x^{0.674}\,e^{-0.000121x}$ x = ozone generation capacity—*kg/d*		81			16			3
Ozone contact chamber	CC = $1{,}771.4\,x^{0.5967} - 1{,}700$ x = chamber volume—m^3	6		19	31	44			
Liquid alum feed	CC = $13{,}223.3\,x^{0.285}\,e^{0.000377x}$ x = liquid feed capacity—*kg/h* (each kg liquid solution ≈ ½ kg commercial dry alum)		64			12	2	7	15
Dry alum feed	CC = $12{,}333.4\,x^{0.3205}\,e^{0.000515x}$ x = dry alum feed—*kg/h*		41			3	4	5	47
Polymer feed	CC = $11{,}760.71\,e^{0.00665x} + 8{,}200$ x = polymer feed—*kg/d*		70			4	1	6	19
Lime feed	CC = $15{,}720 + 1{,}444.5x - 2.7x^2$ x = lime feed—*kg/d*		63			2	5	9	21
Potassium permanganate feed	CC = $9{,}681.7\,x^{0.0304}\,e^{0.00122x}$ x = dry potassium permanganate feed—*kg/d*		34			5	10	32	19
Sulfuric acid feed	CC = $6{,}010.6\,x^{0.7934} + 8{,}180$ x = sulfuric acid (93%) feed—m^3/d		60			16	7	10	7
Sodium hydroxide feed	CC = $54.54\,x^{0.8534} + 13{,}780$ x = dry sodium hydroxide feed—*kg/d*		32			5	3	11	49
Ferric sulfate feed	CC = $10{,}613\,x^{0.319}\,e^{0.000393x}$ x = dry ferric sulfate feed—*kg/d*		41			3	4	5	47
Anhydrous ammonia feed	CC = $3{,}849.2\,x^{0.448}\,e^{-0.000035x}$ x = ammonia feed capacity—*kg/d*		56			15	10	10	9

*Applicable ranges of both construction and O&M costs
†A = excavation and site work, B = manufactured equipment, C = concrete, D = steel, E = labor, F = piping and valves, G = electrical equipment and instrumentation, H = housing, I = energy, J = maintenance material, K = labor
‡CC = construction cost (including 15 percent allowance for contingency and miscellaneous)—*dollars*
§O&MC = operation and maintenance cost—*$/year*
**Applicable range of construction cost only
††Applicable range of O&M cost only
‡‡Construction cost is based on weighted composite unit cost of $485/m² of total building area. The current building cost may be obtained by multiplying the total area with the ratio of unit building costs (current unit cost—$/m²)/($485/m²).

funding and for securing engineering design services.

Secondary cost estimates, developed during the design phase of the project, are detailed construction costs. These cost estimates are used to compare and evaluate bids received for construction of the project. Many factors influence the construction costs—plant capacity, design criteria, treatment processes, site conditions and land cost, climate, permit costs, competition among bidders and suppliers, and general local and nationwide economic conditions. Thus, such construction and operation costs cannot be generalized and must be developed for specific projects.

In this article, the generalized construction as well as O&M cost equations for water treatment units are presented. These equations provide a convenient way to develop the preliminary cost estimates of water treatment processes for economic comparisons of project alternatives during the planning phase of the project.

Preliminary cost estimates developed from data

Preliminary cost estimates for a water treatment plant are developed from historical data from similar water treatment plants. The engineer separates the overall existing project costs into appropriate categories and components that may be applicable to the plant being considered.

TABLE 1, Continued

Generalized construction and O&M cost equations and cost components

Process	Operation and Maintenance Cost					
	Equation	Component Cost—*percent*			Applicable Range of x*	
		I	J	K	Minimum	Maximum
Chlorine storage and feed						
Cylinder storage	O&MC§ = $47.6\,x^{0.89} + 6{,}000$	18	18	64	4	4,500
On-site storage tank with rail delivery	O&MC = $13{,}358\,e^{0.95\,(10^{-4})\,x}$	3	35	62	900	4,500
Direct feed from rail car	O&MC = $11{,}670\,e^{0.81\,(10^{-4})x}$	3	42	55	900	4,500
Ozone generation	O&MC = $392.4\,x^{0.919} + 6{,}800$	77	11	12	4	1,600
Ozone contact chamber	O&MC are included with O&M of ozone generation system					
Liquid alum feed	O&MC = $-6{,}880.7\,e^{-0.659\,(10^{-3}x)} + 8{,}700$	59	4	37	2	2,500
Dry alum feed	O&MC = $1{,}205{,}293\,e^{0.1943\,(10^{-4}x)} - 1{,}202{,}070$	17	3	80	4	2,300
Polymer feed	O&MC = $3{,}000.8\,e^{0.00207x}$	24	10	66	0.5	100
Lime feed	O&MC = $1{,}230 + 305.22x - 0.5662x^2$	9	7	84	4	4,500
Potassium permanganate feed	O&MC = $-2{,}125.9e^{-0.01689x} + 5{,}600$	5	3	92	0.5	230
Sulfuric acid feed	O&MC = $-42{,}397.4\,e^{-0.682\,(10^{-2})x} + 43{,}670$	5	4	91	0.04	20
Sodium hydroxide feed	O&MC = $1{,}500 + 0.6233x + 0.618^{(10^{-4}x^2)}$	35	5	60	4	4,500
Ferric sulfate feed	O&MC = $1{,}260{,}926\,e^{0.1394\,(10^{-4}x)} - 1{,}257{,}710$	17	2	81	6	3,000
Anhydrous ammonia feed	O&MC = $-28{,}063\,e^{-0.241\,(10^{-3}x)} + 36{,}160$	6	40	54	110	2,300

*Applicable ranges of both construction and O&M costs

†A = excavation and site work, B = manufactured equipment, C = concrete, D = steel, E = labor, F = piping and valves, G = electrical equipment and instrumentation, H = housing, I = energy, J = maintenance material, K = labor

‡CC = construction cost (including 15 percent allowance for contingency and miscellaneous)—*dollars*

§O&MC = operation and maintenance cost—*\$/year*

**Applicable range of construction cost only

††Applicable range of O&M cost only

‡‡Construction cost is based on weighted composite unit cost of \$485/m^2 of total building area. The current building cost may be obtained by multiplying the total area with the ratio of unit building costs (current unit cost—\$/m^2)/(\$485/m^2).

TABLE 1, Continued

Generalized construction and O&M cost equations and cost components

Process	Construction Cost								
	Equation	Component Cost—*percent*							
		A†	B	C	D	E	F	G	H
Aqua ammonia feed	$CC = 2{,}191.3\,x^{0.368}\,e^{0.000077x}$; x = ammonia feed capacity—*kg/d*		74			6	5	15	
Powdered activated carbon	$CC = 2{,}506\,x^{0.7504} + 63{,}780$; x = carbon feed—*kg/h*	1	54	3	5	6	12	17	2
Rapid mix									
$G = 300\ s^{-1}$	$CC = 239.7\,x^{1.055} + 13{,}640$	3	36	7	12	18		24	
$G = 600\ s^{-1}$	$CC = 361.2\,x^{1.025} + 13{,}840$	2	45	6	10	16		21	
$G = 900\ s^{-1}$	$CC = 673.8\,x^{1.014} + 13{,}920$; x = total basin volume—*m^3*	1	68	4	6	14		7	
Flocculator									
$G = 20\ s^{-1}$	$CC = 5{,}610.0\,x^{0.494}\,e^{0.000024x}$	5	17	15	21	24		18	
$G = 50\ s^{-1}$	$CC = 4{,}922.0\,x^{0.522}\,e^{0.0000247x}$	4	25	13	18	24		16	
$G = 80\ s^{-1}$	$CC = 4{,}216.1\,x^{0.5616}\,e^{0.0000286x}$; x = total basin volume—*m^3*	3	35	10	14	25		13	
Clarifier									
Circular	$CC = 64{,}720 + 353.1x - 0.02285x^2$	2	31	7	39	13	5	3	
Rectangular	$CC = 30{,}290 + 537.2x$; x = basin surface area—*m^2*	4	27	10	27	20	10	2	
Gravity filter structure	$CC = 35{,}483.4\,x^{0.591}\,e^{0.000162x}$; x = filter area—*m^2*	1	20	6	5	21	23	6	18
Filtration media									
Stratified sand	$CC = 92.6\,x^{0.992} + 4{,}100$		100						
Dual media	$CC = 846.0\,x^{0.7432}\,e^{0.000153x}$		100						
Mixed media	$CC = 1{,}241.1\,x^{0.7485}\,e^{0.000183x}$; x = filter bed area—*m^2*		100						
Filter backwash pumping	$CC = 36{,}000 + 1{,}254.21x - 0.1212x^2$; x = filter surface area—*m^2*		47			7	24	22	
Surface wash system									
Hydraulic	$CC = 9{,}704.1\,x^{0.399}\,e^{0.00046x}$		60			10	10	20	
Air water	$CC = 32{,}419.9\,x^{0.297}\,e^{0.00025x}$; x = total filter area—*m^2*		33			9	48	10	
Wash water surge basin	$CC = 19{,}460 + 784.0x - 0.2839x^2$; x = basin capacity—*m^3*	1		31	18	43	5	2	
Wash water storage tank	$CC = 257.4\,x^{0.842}\,e^{0.0000073x}$; x = storage volume—*m^3*	1		1	45	53			
Clear water storage below ground	$CC = 583.2\,x^{0.78} + 22{,}900$; x = capacity—*m^3*	2		40	25	31		2	
Finished-water pumping TDH—30.48 m (100 ft)	$CC = 8.76\,x^{0.892} + 17{,}390$; x = pumping capacity—*m^3/d*		52			9	17	22	
Raw water pumping	$CC = 2.098\,x^{0.9624} + 18{,}700$; x = pumping capacity—*m^3/d*		43			14	26	17	
Gravity sludge thickener	$CC = 15{,}530.1\,x^{0.6523}\,e^{0.0101x}$; x = thickener diameter—*m*	4	41	12	16	26		1	
Sludge dewatering lagoons	$CC = 29.5\,x^{0.793} + 2{,}200$; x = effective storage volume—*m^3*	53		4	1	26	16		
Sand drying beds	$CC = 4{,}540 + 35.25x - 0.000346x^2$; x = total bed area—*m^2*	5		10	3	57	25		
Filter press	$CC = 259{,}489.8\,x^{0.591} + 135{,}900$; x = total filter press volume—*m^3*		64			18	1		17
Belt filter press	$CC = 170{,}640 + 15{,}196.21\,x$; x = total installed machine capacity—*m^3/h*		68			20	2	1	9
Administration, laboratory, and maintenance building‡‡	$CC = 235.66\,x^{0.5613} + 1{,}220$; x = plant capacity—*m^3/d*								

*Applicable ranges of both construction and O&M costs
†A = excavation and site work, B = manufactured equipment, C = concrete, D = steel, E = labor, F = piping and valves, G = electrical equipment and instrumentation, H = housing, I = energy, J = maintenance material, K = labor
‡CC = construction cost (including 15 percent allowance for contingency and miscellaneous)—*dollars*
§O&MC = operation and maintenance cost—*\$/year*
**Applicable range of construction cost only
††Applicable range of O&M cost only
‡‡Construction cost is based on weighted composite unit cost of \$485/m^2 of total building area. The current building cost may be obtained by multiplying the total area with the ratio of unit building costs (current unit cost—\$/m^2)/(\$485/m^2).

TABLE 1, Continued

Generalized construction and O&M cost equations and cost components

Process	Operation and Maintenance Cost					
		Component Cost—*percent*			Applicable Range of x*	
	Equation	I	J	K	Minimum	Maximum
Aqua ammonia feed	O&MC = $-861.9\ e^{-0.461\ (10^{-4}x)} + 2{,}500$	1	17	82	110	2,300
Powdered activated carbon	O&MC = $1{,}153.44\ x^{0.6539} + 9{,}650$	30	26	44	1.5	3,000
Rapid mix						
$G = 300\ s^{-1}$	O&MC = $38.4\ x^{1.1086} + 4{,}750$	53	1	46	3	550
$G = 600\ s^{-1}$	O&MC = $88.6\ x^{1.0608} + 4{,}760$	69	1	30	3	550
$G = 900\ s^{-1}$	O&MC = $337.3\ x^{1.0196} + 4{,}760$	88	0	12	3	550
Flocculator						
$G = 20\ s^{-1}$	O&MC = $15.2\ x^{0.7724} + 1{,}160$	12	60	28	50	28,000
$G = 50\ s^{-1}$	O&MC = $12.5\ x^{0.8437} + 1{,}180$	44	38	18	50	28,000
$G = 80\ s^{-1}$	O&MC = $13.5\ x^{0.8976} + 1{,}180$	76	16	8	50	28,000
Clarifier						
Circular	O&MC = $24.94\ x^{0.724} + 1{,}330$	4	36	60	60	3,000
Rectangular	O&MC = $8.4\ x^{1.0386} + 1{,}900$	4	16	80	20	450
Gravity filter structure	O&MC = $359.5\ x^{0.8568} + 8{,}100$	36	12	52	13	2,600
Filtration media						
Stratified sand	O&MC are included with O&M of filter structure costs.				13	2,600
Dual media					13	2,600
Mixed media					13	2,600
Filter backwash pumping	O&MC = $73.3\ x^{0.75} + 2{,}200$	52	24	24	8** 13†	140** 2,600††
Surface wash system						
Hydraulic	O&MC = $72.3\ x^{0.7014} + 380$	51	5	44	13	2,500
Air water	O&MC = $73.5\ x^{0.7509} + 2{,}180$	53	24	23	13	2,500
Wash water surge basin	O&MC are included with O&M costs of backwash pumping and surface wash system.				35	1,800
Wash water storage tank	O&MC are included with O&M costs of backwash pumping and surface wash system.				75	3,500
Clear water storage below ground	O&MC are included with finished-water pumping costs.				40	30,000
Finished-water pumping TDH—30.48 m (100 ft)	O&MC = $0.502\ x^{0.9985} + 5{,}200$	88	4	8	5,500	1,135,500
Raw water pumping	O&MC = $5{,}530 + 0.68879x$	81	6	13	3,500	756,000
Gravity sludge thickener	O&MC = $21.3\ x^{1.4736} + 1{,}200$	8	29	63	6	45
Sludge dewatering lagoons	O&MC = $6.473\ x^{0.9124} - 45$	6	1	93	300	140,000
Sand drying beds	O&MC = $2.176\ x^{1.074} + 5{,}810$	6	6	88	450	37,200
Filter press	O&MC = $797{,}615.7\ e^{0.01387x} - 725{,}720$	13	3	84	0.12	25
Belt filter press	O&MC = $584{,}735.8e^{0.001522x} - 568{,}030$	35	13	52	3	200
Administration, laboratory, and maintenance building‡‡	O&MC = $4{,}568.66\ x^{0.2935} - 32{,}000$	13	9	78	3,500	750,000

*Applicable ranges of both construction and O&M costs
†A = excavation and site work, B = manufactured equipment, C = concrete, D = steel, E = labor, F = piping and valves, G = electrical equipment and instrumentation, H = housing, I = energy, J = maintenance material, K = labor
‡CC = construction cost (including 15 percent allowance for contingency and miscellaneous)—*dollars*
§O&MC = operation and maintenance cost—*\$/year*
**Applicable range of construction cost only
††Applicable range of O&M cost only
‡‡Construction cost is based on weighted composite unit cost of \$485/m^2 of total building area. The current building cost may be obtained by multiplying the total area with the ratio of unit building costs (current unit cost—\$/m^2)/(\$485/m^2).

TABLE 2
BLS and ENR indexes used as basis for the construction cost curves

Cost Component	Index	October 1978 Value of Index	Modified October 1978 Value of Index	Updated April 1992 Value of Index
Excavation and sitework	ENR Skilled Labor Wage Index	247.0 (1967 = 100)	247.0 (1967 = 100)	455.0 (1967 = 100)
Manufactured equipment	BLS General Purpose Machinery and Equipment–Commodity Code 114	221.1 (1967 = 100)	72.9 (1982 = 100)	130.0 (1982 = 100)
Concrete	BLS Concrete Ingredients Commodity Code 132	221.1 (1967 = 100)	71.6 (1982 = 100)	119.4 (1982 = 100)
Steel	BLS Steel Mill Products Commodity Code 1017	262.1 (1967 = 100)	75.0 (1982 = 100)	107.4 (1982 = 100)
Labor	ENR Skilled Labor Wage Index	247.0 (1967 = 100)	247.0 (1967 = 100)	455.0 (1967 = 100)
Pipes and valves	BLS Valves and Fittings Commodity Code 114901	236.4 (1967 = 100)	70.2 (1982 = 100)	139.6 (1982 = 100)
Electrical equipment and instrumentation	BLS Electrical Machinery and Equipment–Commodity Code 117	167.5 (1967 = 100)	72.3 1982 = 100)	121.3 (1982 = 100)
Housing	ENR Building Cost Index	254.8 (1967 = 100)	254.8 (1967 = 100)	415.9 (1967 = 100)

TABLE 3
Construction and operation and maintenance cost components and updated values in current dollars

Cost Components	October 1978		Updated April 1992 Cost		
	Component *percent*	Cost *$*	Modified Index Value Basis	Index Value	Updated Cost—*$/year*
Construction cost					
A. Excavation and site work	4	9,807	247.0	455.0	18,070
B. Manufactured equipment	27	66,196	72.9	130.0	118,050
C. Concrete	10	24,517	71.6	119.4	40,900
D. Steel	27	66,196	75.0	107.4	94,800
E. Labor	20	44,034	247.0	455.0	81,120
F. Piping and valves	10	24,517	70.2	139.6	48,800
G. Electrical equipment and instrumentation	2	4,903	72.3	121.3	8,230
H. Housing			254.8	415.9	
		245,170			410,000
Operation and maintenance costs					
I. Energy requirements	4	246	\$0.03/kW·h	\$0.05/kW·h	410
J. Maintenance material requirements	16	981	71.6	122.2	1,670
K. Labor requirements	80	4,907	\$10.00/hour	\$19.00/hour	9,320
L. Chemical use and related cost		0			0
		6,134			11,400

Cost data for different years are normalized to a common base using appropriate cost indexes. Thus, cost information for specific projects may be developed from the completed projects. In many cases, developing specific project costs from historical data may not be possible because of the unreliability of the data and the possibility of gross errors occurring when overall project costs are separated into individual components. In such cases, cost information published by federal agencies, professional journals, and private organizations is used. Familiarity and special care are needed in using these cost curves so that large project components are not overlooked or included more than once. In August 1979, the US Environmental Protection Agency (USEPA) published a four-volume report presenting construction and O&M cost curves for 99 unit processes useful for removing contaminants included in the National Interim Primary Drinking Water Regulations.[2] The USEPA report is the basis for developing the generalized cost equations presented here for estimating construction and O&M costs of a conventional water treatment plant.

Generalized construction costs determined from aggregate data

The generalized construction costs presented in the USEPA report used equipment cost data supplied by manufacturers, conceptual designs, and published data. The construction cost of each process was developed by determining and then aggregating the cost of eight principal components: excavation and sitework (A), manufactured equipment (B), concrete (C), steel (D), labor (E), piping and valves (F), electrical equipment and instrumentation (G), and housing (H). The subtotal of the costs of these eight categories includes the cost of materials and equipment purchase and installation as well as subcontractors' overhead and profit. A 15 percent allowance has been added to this subtotal to cover miscellaneous and contingency items. Construction costs, however, do not include costs for special sitework, general contractors' overhead and profit, engineering, land or legal costs, fiscal, or administrative and interest costs during construction. These cost items are all more directly related to the total cost of a project than to the cost of the individual unit processes. Therefore, these cost items are most appropriately added following summation of the cost of the individual unit processes.

Cost equations developed via computers. Generalized equations for construction costs were generated by using a computer program called PLOTIT®, an interactive graphics and statistics program.[3] Data used to generate these equations were obtained from the USEPA report.[2] The procedure is relatively simple. First, a two-dimensional input file is created in the format the program needs. Then, the type of equation for fitting the data point is selected. For example, the equation selected could be linear, quadratic, or exponential. The program then computes the coefficients for the equation based on best line or curve generated. This process is repeated for several types of equations, and the one that best represents the data is chosen.

Forty-two generalized construction cost equations are given in Table 1. Each equation represents a unit process and a chemical feed system most commonly used in a conventional water treatment plant. The applicable range of each curve (minimum and maximum limit) and the percent cost components are also provided. For example, construction and O&M cost equations for chlorine storage and a feed system using a chlorine cylinder (Item 1a, Table 1) have an applicable range of 4 kg/d (10 lb/d) to 4,500 kg/d (10,000 lb/d). The major construction cost components are 47 percent manufactured equipment (B), 6 percent labor (E), 4 percent piping and valves (F), 5 percent electrical equipment and instrumentation (G), and 38 percent housing (H). The equation representing the October 1978 construction cost is

$$CC = 680.75\,x^{0.763} + 11{,}010$$

in which CC = construction cost (dollars) and x = chlorine feed capacity (kg/d).

Cost index used to adjust estimates. The most common method used to adjust cost estimates from one geographic location and time period to another is the cost index. An index is simply a calculated numerical value that is a function of an established quantity of material and labor. The key advantage of a single index is the simplicity with which it can be applied. Although use of a single index is an uncomplicated approach, there is much evidence to indicate that these time-honored indexes are often inadequate for application to water utility construction. Thus, a procedure to update several cost components is desirable.

The most frequently utilized single indexes in the construction industry are the *Engineering News Record* (ENR) construction cost index (CCI), and the ENR building cost index (BCI).[4] The key advantages of ENR indexes are their availability, simplicity, and geographic specificity. Unfortunately, these indexes do not include mechanical equipment, instrumentation, or piping and valves; also, a proportionate mix of labor and material is not specific to the construction of water treatment plants. To overcome these shortcomings of ENR indexes, the total construction costs are divided into eight major cost components. The Bureau of Labor Statistics (BLS) and ENR indexes for these cost components for 1967 and 1978 dollars are given in Table 2. Thus, total cost is updated based on eight principal cost components by using appropriate indexes rather than a single index.

Although use of a single index is an uncomplicated approach, there is much evidence to indicate that these time-honored indexes are often inadequate for application to water utility construction.

Updating costs for ENR CCIs is straightforward. The current ENR value for each desired category is obtained from the most recent issue of ENR. This value is divided by the index value for October 1978 and multiplied by 1978 construction cost to obtain the current construction cost.[5,6]

Current construction cost =

October 1978 construction cost × (current ENR CCI index/October 1978 CCI index)

Updating costs using the BLS producer price index (PPI) is more complicated than using ENR indexes. In 1978, BLS indexed costs using 1967 as a basis (1967 = 100).[7] In 1992, BLS indexes costs using 1982 as a basis (1982 = 100).[8] So that costs may be updated for categories in which the basis for indexing has been changed, BLS provides documents called historicals. A historical tabulates the entire history of index figures for a single category in the PPI, using the current basis (1982 = 100).[8] The BLS provides historicals free of charge. They may be obtained by contacting the most convenient BLS regional office and requesting a historical for each category under study.

Using these historicals, BLS PPI figures for 1978 are replaced in the calculation of current construction cost by a historical index figure that uses the same basis as current PPIs. These modified indexes also appear in Table 2.

For the BLS category, "valves and fittings," for which figures are no longer being indexed, an alternate category has been selected to replace it, "miscellaneous general purpose equipment" (PPI commodity code 1149). This category was chosen over several others, such as "metal valves except fluid power," "plumbing and heating valves," and "metal pipe flanges, fittings and unions." The "miscellaneous general purpose equipment" category yields a median figure, compared with figures yielded by other categories. In addition, index figures for it are available from BLS and need no extrapolation or averaging.

The current construction cost components are then calculated in the same way as when the ENR indexes are used. The updated April 1992 BLS and ENR indexes are also provided in Table 2.[9] The procedure for using BLS indexes for cost updating is given here.

Suppose the total construction cost of a rectangular clarifier is $3 million and the percent cost of manufactured equipment is 27 percent or $810,000. The October 1978 modified value of BLS "general purpose machinery and equipment" (commodity code 114) is 72.9. The April 1992 value of index is 130.0. This cost component can be updated using current and modified cost indexes. The updated cost for the "manufactured equipment" component is 1.44 million dollars. Other cost components can also be updated to provide total updated construction cost.

O&M costs defined

Total operation and maintenance costs are based on energy requirements, maintenance material requirements, and labor requirements. The energy category includes process energy and building energy. All energy components (such as diesel fuel, electricity, and natural gas) are expressed in terms of kilowatt-hours (kW·h) per year. The annual energy cost is based on unit costs of $0.03/kW·h of electricity.

O&M cost equations also developed via computer. The generalized O&M cost equations were also generated using the computer program PLOTIT.[3] The USEPA report served as the data source for these equations.[2] Thirty-five generalized O&M cost equations for many unit processes are given, along with the construction cost equations in Table 1. The applicable range of these equations and the percentages for three cost components (energy, maintenance, and labor) are also provided in this table.

Costs updated through three components. Updating of O&M costs may be accomplished by updating the three individual components: energy, labor, and maintenance material. The energy and labor costs are updated in proportion to the current unit costs of electrical power (\$/kW·h) and labor rate (\$/hour). Maintenance material costs are updated using the PPI for finished goods. The maintenance material costs used in cost development are based on October 1978 BLS PPI for finished goods of 199.7.[2,7] Because this number comes from reports that used 1968 = 100 as a basis, it must be modified.

Actual costs depend heavily on the site conditions, climate, competition among bidders and suppliers, and general local and nationwide economic conditions.

Using BLS PPI historicals, 199.7 is replaced with a modified index value (1982 = 100) of 71.6.[8] The current April 1992 PPI for finished goods is 122.2.[9] The cost of chemicals required for process operation must also be added to obtain total O&M costs. Expected chemical costs can be readily obtained from prospective suppliers.

Equivalent cost and present worth must be determined to compare alternatives

The procedure for cost comparison of alternatives includes determination of the present worth and equivalent annual costs for each project alternative. The present worth may be thought of as the sum that, if invested now at a given rate, would provide exactly the funds required to make all necessary expenditures during the planning period. Equivalent annual cost is the expression of a nonuniform series of expenditures used as a uniform annual amount to simplify calculations of present worth. Detailed procedures for making these calculations are explained in many textbooks.[10–12]

The present worth of annual O&M cost, capital recovery factor, and equivalent annual costs is obtained from Eqs 1, 2, and 3.

Present worth of annual O&M cost, \$ =

$$[\text{total annual O\&M cost}]\ \frac{[1-(1+i)^{-n}]}{i} \quad (1)$$

$$\text{Capital recovery factor} = \frac{i\,(1+i)^n}{[(1+i)^n-1]} \quad (2)$$

Equivalent annual costs, \$/y = project present worth (capital recovery factor) (3)

in which i = interest rate; n = design period, y; and y = years.

The procedure for developing the costs for unit comparison is shown in the following example. Calculate the construction, O&M costs, total present worth, total capital recovery factor, and equivalent annual cost for a rectangular clarifier that has a total surface area of 400 m^2. The interest rate is 6 ¼ percent, and the design period is 15 years.

- Calculate total construction cost, including 15 percent miscellaneous and contingency items (October 1978 dollars). The construction cost equation (taken from Table 1) is: CC = 30,290 + 537.2 x, in which x = basin surface area, m^2. Thus, CC = 30,290 + 537.2 (400) = \$245,170.
- Calculate the O&M cost. The O&M cost equation is O&MC = 8.4 $x^{1.0386}$ + 1,900 = \$6,134/y.
- To update costs, the components of capital and O&M costs in various categories are calculated using the percent component data given in Table 1. These cost components, updated to current dollars, are provided in Table 3. The updated April 1992 construction cost of the example clarifier is \$410,000. Add to this value the special costs of general contractor's overhead and profit, engineering, land, legal, fiscal, administrative, and interest costs during construction. These costs may vary considerably for different projects. Assume these costs represent 28 percent of the construction costs. Thus, total construction cost of the basin, including these special costs, is \$525,000.

The present worth of annual O&M cost, capital recovery factor, total project present worth and equivalent annual cost are calculated from Eqs 1, 2 and 3. These values are:

Present worth of annual O&M cost	= \$109,000
Capital recovery factor	= 0.10465
Total project present worth	= \$109,000 + \$525,000 = \$634,000
Equivalent annual cost	= \$66,400/ year

Generalized construction as well as O&M cost equations for water treatment processes provide a convenient way to develop preliminary cost estimates of such processes during the planning phase. The capital cost updating procedure uses ENR and BLS indexes for eight cost component categories.

The total present worth and the equivalent annual costs calculated from these equations are used to compare the economics of the alternative treatment processes and major project components in order to arrange for project funding and to secure engineering design services.

The cost estimates developed from these generalized equations do not represent the actual construction and O&M costs of a project. Actual costs depend heavily on the site conditions, climate, competition among bidders and suppliers, and general local and nationwide economic conditions. Therefore, actual construction and operation costs cannot be generalized and must be developed for each specific project.

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