Appendix 7-3

Description of Calculation Factors For Computer Program “COST”

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The following sections describe the calculations involved in the FORTRAN computer program COST and its subroutines. The program uses functional relationships to calculate facility sizes, quantities, and costs. Not all of the features of the COST program were used in specific applications related to the El Paso County Water Master Plan.

Wells, Pumps and Interwell Pipe (Subroutine WELL)

Number of Wells

The number of wells is equal to the peak flow rate in gpm divided by the yield per well in gpm, rounded up, plus a standby capacity of 10 percent of the total number of wells. The standby capacity, however, cannot be less than one or greater than 10 wells as given by the following equations:

$$\text{NWA} = \text{peak flow rate/yield per well (rounded up)}$$

$$\text{Number of wells} = \text{NWA} + 10 \text{ percent NWA}$$

where $1 \leq 10 \text{ percent NWA} \leq 10$.

Cost of Pumps

The cost of the pumps is calculated from the following equation:

$$\text{Cost per pump} = (0.28 \times \text{yield per well in gpm} \times \text{pumping lift in ft}) + 8{,}200.$$

Cost of Well Construction

The cost of well construction is calculated from the following equation:

$$\text{Cost per well} = (150. \times \text{depth of well in ft}) - 2{,}200.$$

Cost of Interwell Pipe

The cost of interwell pipe is related to the peak flow rate in gpm and the number of wells, and is given by the following equation:

$$\text{Cost of interwell pipe} = 27{,}000. \times (\text{peak flow rate} \times \text{number of wells})^{0.65}$$

Total Cost of Wells

The total cost of wells is the sum of the pump cost, well construction cost, and interwell pipe cost.

Transmission Pipe (Subroutines SIZE, PIPE, TERM and BOOST

Size of Pipe (Subroutine SIZE)

The pipe diameter is obtained from a pipe-size optimization formula by Streeter (1973). Because pipe is available only in certain diameters, the size calculated by the formula was rounded up to the next six-inch interval for pipe diameters less than 48 inches, and rounded up to the next 12-inch interval for pipe diameters greater than 48 inches. The pipe-size formula is given by:

$$d(inches) = 83.4 \frac{P^{0.163} Q^{0.463}}{E^{0.163} C^{0.301}}$$

where P is the cost of electricity in \$/kwh, Q is the peak flow rate in mgd, E is the pumping plant efficiency, and C is the Hazen-Williams roughness coefficient for the pipe being used.

Length of Pipeline and Cost of Pipe (Subroutine PIPE)

The length of pipeline is equal to the measured miles times a factor which is greater than 1.0 to allow for terrain corrections. The cost per foot of pipe is derived from recent bid tabulations from various Front Range projects. For welded steel pipe, the relationship between in-place pipe cost on a unit basis and pipe diameter is given by:

Cost per foot = 4.5451 x (pipe diameter in inches) – 10, for $d \leq 24$”,
Cost per foot = 10.1667 x (pipe diameter in inches) – 163, for $d > 24$”.

Cost of Terminal Storage (Subroutine TERM)

If terminal storage is used, it consists of tanks. There must be at least two tanks and no tank may hold more than 25 million gallons. The total storage capacity must be at least equal to two days design usage. The number of tanks is related to design usage in mgd by the following equation:

Number of tanks = 2

if usage is $\leq$ 25 mgd.

Number of tanks = 1 + (2 x usage in mgd/25) (rounded up) if usage is > 25 mgd. The size of terminal storage tanks is arbitrarily set so the height of the tank is equal to the tank radius. The cost of the terminal storage tanks is calculated by the following equation:

Cost of tanks = Number of tanks x ((0.18295 x usage in mgd) + 0.06246) x 10^6.

Cost of Booster Stations (Subroutine BOOST)

The cost of booster stations is a function of pipe friction losses, elevation head, height of terminal storage facilities and discharge head at the well pumps. If the water source is surface water, the discharge head at well pumps is set equal to zero.

Friction head is obtained from the Hazan-Williams formula as given in Davis and Sorensen (1969):

$$S = \frac{Q^{1.852}}{\left(0.432 C_w d^{2.63}\right)^{1.852}}$$

where S is head loss in ft/ft, Q is peak flow rate in cfs, C_w is the Hazen-Williams coefficient, and d is the pipe diameter in ft. The total booster station pumping head is equal to the friction loss from the above equation, plus the elevation head, plus the height of the terminal storage tanks, minus the discharge head at the well pumps.

The number of booster stations is equal to the following:

Number of large booster stations = (Total head/240 ft) (rounded down).

If the remainder, R, before rounding is greater than 0.2, there will be one small booster station pumping at R x horsepower. If R is less than or equal to 0.2, then R = 0 and additional stages are added to well pumps to decrease the total head required for booster stations.

The horsepower of each booster station is given by the following (Singh, 1971):

Horsepower (H) = 0.1756 x peak flow in mgd x head per station x J/(pump efficiency).

Head per station is set equal to 240 feet. J in the horsepower equation is the firming or standby factor and is given by the following, where X is the design flow rate in mgd:

$X < 2.0$	$J = 2.08 - 0.18X$
$2.0 \leq X \leq 5.0$	$J = 1.9666 - 0.1233X$
$5.0 \leq X \leq 10.0$	$J = 1.42 - 0.014X$
$10.0 \leq X \leq 20.0$	$J = 1.30 - 0.002X$
$20.0 \leq X \leq 30.0$	$J = 1.28 - 0.001X$
$30.0 < X$	$J = 1.25$

The cost per booster station is given by the following equation (Singh, 1971):

$$\text{Cost of all booster stations} = (17{,}000. + (135. \times (\text{Horsepower})^{1.01})) \times \text{number of stations} + (17{,}000. + (135. \times (R \times \text{Horsepower})^{1.01})).$$

Water Treatment Plant (Subroutine TREAT)

Water treatment plant costs assume that both ground water and surface water will be treated at a central treatment plant. The plant will treat raw water for radon, methane, hydrogen sulfide, iron (with arsenic co-precipitation), colloids, and manganese. The unit processes are assumed to include aeration, chemical precipitation, clarification, sand filtration, and disinfection. The construction cost per million gallons per day of treatment plant capacity was estimated from contract unit rates for the processes identified above, and include in-plant pumping and piping. Three different plant capacities were used to give the following water treatment plant construction cost:

$$\text{Cost of water treatment} = 762{,}304 \times (\text{peak flow in mgd})^{0.6507}.$$

Construction Costs (COST)

Total construction costs are equal to the cost of wells, plus pipeline, plus terminal storage, plus booster stations, plus water treatment.

Interest During Construction (Subroutine INTR)

Interest during construction is a function of the construction period, the interest rate, and the construction cost. The construction period is determined using the following equation and applied to the design capacity in mgd:

$$\text{Number of months of construction (M)} = \frac{8.0}{(1/mgd)^{0.32}} \text{ (rounded up).}$$

The cost of interest during construction is given by the following:

$$\text{Interest} = (((\text{annual interest rate})/12.) \times M) \times \text{Construction costs}$$

Electric Power Costs (Subroutine ELEC)

It takes 0.004 kwh to lift 1,000 gallons of water one foot (Streeter, 1973). As defined above, Head is the sum of the friction head, plus elevation head, plus height of terminal storage, plus pump discharge head. Thus, the annual cost of electric power is given by:

$$\text{Electric power costs} = P \times (0.004 \times (\text{design flow in gal/yr})/1000) \times \text{Head}$$

Where P is the electric power cost in dollars per kwh.

O& M Labor, Supplies and Materials (Subroutine OM)

The water supply, treatment, and transmission costs of operation and maintenance (O & M) labor, supplies, and materials is related to peak flow rate, number of wells, and miles of transmission pipeline. The cost of O & M labor, supplies and materials for water supply and transport is given by:

$$\text{Cost of O \& M} = 3{,}262 \times (\text{peak flow in mgd} \times \text{number of wells} \times \text{number of miles of transmission pipeline})^{0.49}.$$

The water treatment cost of O & M labor, supplies, and materials is related to the peak flow rate and is given by:

$$\text{Cost of O \& M} = 475{,}655 \times (\text{peak flow in mgd}) + 375{,}893.$$

Total O & M Costs

The total O & M costs are the sum of the electric power costs and the O & M labor, supplies and materials costs.

Working Capital and Start-Up Costs (Subroutine WCSU)

The costs of working capital and project start up are included to represent additional costs incurred for these aspects of a water resources project. The working capital costs are assumed to be comprised of two months of total O & M costs. Start-up costs are assumed to be one month of total O & M costs. The equations for working capital and start-up costs are given by:

$$\text{Cost of working capital} = 0.1667 \times (\text{Total O \& M}),$$

and

$$\text{Cost of start-up} = 0.0833 \times (\text{Total O \& M}).$$

Owner's General Expense (Subroutine OGE)

This cost factor is derived from scaling factors given by Streeter (1973), which vary with total construction cost, C. These scaling factors are given by the following equations:

$$\text{factor} = [0.12/(1{,}000{,}000/C)^{-0.125}], \quad \text{for } C \le \$10{,}000{,}000$$
$$\text{factor} = [0.09/(10{,}000{,}000/C)^{-0.109}], \quad \text{for } C > \$10{,}000{,}000.$$

The owner's general expense, then, is calculated as:

$$\text{Owner's general expense} = C \times \text{factor}.$$

Land Costs (Subroutine LAND)

The land requirements for pumping, transmission, and treatment of water in El Paso County were assumed as follows:

0.5 acre per well site;
0.25 acre per booster station;
30-ft wide right-of-way for pipeline; and
100-ft clearance around terminal storage tanks.
Water treatment plant land required, in acres, was calculated from

$$A = 0.56065 \times (\text{peak flow rate in mgd}) + 0.41.$$

The total land cost is the total acreage of land times the price per acre of land.

Annual Depreciable and Non-Depreciable Capital Costs (COST)

The annual depreciable capital costs are a function of the depreciable capital rate, the tax rate, and the insurance rate. The depreciable capital rate, DCR, is equal to the amortization factor, plus the interest rate, plus the tax rate, plus the insurance rate (Streeter, 1973). The amortization factor plus the interest rate is called the capital cost recovery factor, CRF, and is defined by Singh and others (1972) as:

$$CRF = \frac{i(1+i)^N}{(1+i)^{N-1}}$$

where N is the amortization period in years and i is the annual interest rate.

The DCR is then given by

$$DCR = CRF + \text{tax rate} + \text{insurance rate}.$$

The total depreciable capital costs are equal to the total construction cost, plus interest during construction, plus start-up cost, plus owner's general expense. Annual depreciable capital costs equal the total depreciable capital costs times DCR.

Total non-depreciable capital costs equal the sum of land costs, plus working capital. The annual non-depreciable capital costs equal the total depreciable capital costs times and annual interest rate, i.

Total Annual Costs (COST)

Total annual costs include the total annual O & M, plus total annual depreciable capital cost, plus total annual non-depreciable capital cost (Streeter, 1973). The unit annual cost, or cost per unit of water pumped/moved/treated, is the total annual cost divided by the design water usage.

Inflation Factor

The following costs are multiplied by the inflation factor:

water treatment plant costs;
total well costs;
terminal storage costs;
booster stations costs; and
O & M labor, supplies and materials costs.

References

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