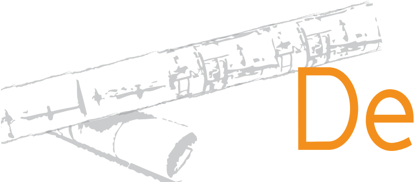


Design Data 25

American
Concrete Pipe
Association

Life Cycle Cost Analysis

Selecting pipe materials best suited for service as a storm sewer, culvert, sanitary sewer, or small bridge replacement is of primary importance to the design engineer. Selection is based on hydraulic efficiency, structural integrity, durability and cost. On many projects when alternate materials are bid, selection is too often based on the initial cost. However, the pipe material with the lowest first cost may not be the most economical selection for the design life of the project.

Thus the application of least (life cycle) cost analysis to road and drainage projects has increased dramatically in recent years. Local and state governments have increasingly included some type of analysis in their material selection process. The importance of considering the future of a facility during the design phase has been made clear by the multitude of problems many authorities are facing as our infrastructure declines. In many instances, engineers and executive officers are having to repair and replace integral sections of infrastructure that have experienced premature degradation.

According to the U.S. Army Corps of Engineers, selection of all systems, components, and materials for Civil Works projects are based on their long-term performance, including a life cycle cost analysis. This design criteria is referred to as Regulation No. 1110-2-8159. The cost consideration in a project must be based on the long-term performance of the material being used, not just on the initial cost. It is policy that the design engineers are responsible for implementing life cycle design concepts into the project development process.

The American Society for Testing and Materials (ASTM), Committee C-13 on Concrete Pipe, has developed and published ASTM Standard of Practice C-1131 for Least Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer and Sanitary Sewer Systems. ASTM has also developed Practice A-930 for Least Cost Analysis of Corrugated Metal Pipe, and Practice F-675 for Least Cost Analysis of Plastic Pipe.

The practice covers procedures for using life cycle analysis (LCA) techniques to evaluate alternative pipeline materials, structures or systems that satisfy the same functional requirement. The LCA technique evaluates the present value constant dollar costs to install and maintain alternative drainage systems including planning, engineering, construction, maintenance, rehabilitation and replacement and cost deductions for any residual value at the end of the proposed project design life. The decision maker, using the results of the LCA can then readily identify the alternative with the lowest total cost based on the present value of all initial and future costs.

The ACPA has used ASTM C1131 to develop a comprehensive LCA practice which eliminates unreliable assumptions, resulting in a readily usable and accurate design aid. The practice uses the well established economic principles of present value which has been used by economists and other professionals for decades. However, the method does require certain assumptions regarding future interest and inflation trends.

The design and construction of pipelines, culverts and related drainage facilities are important areas of engineering, and like all engineering projects, decisions must be made regarding material and/or system selection. Material selection with development of appropriate design criteria is a very involved undertaking relating years of experience, usage and performance. The proper engineering design of any hydraulic structure requires consideration of the different but interrelated fields of:

- Planning
- Specifications
- Hydrology
- Hydraulics
- Structures
- Installation
- Durability
- Maintenance
- Economics

The first six aspects of pipe and drainage design are fairly well established. However, the durability and economic aspects are generally not given proper consideration and for many projects, pipe materials or systems are selected on an initial (or capital) cost basis only. However, lower capital cost does not always result in the most economical product or system. To determine the most economical choice, the principles of economics must be applied through a life cycle cost analysis. In such analyses all factors affecting the cost effectiveness must be evaluated. The ASTM Standard Practice includes the following factors:

- Project design life
- Material service life
- First cost
- Interest (discount) rate
- Inflation rate
- Maintenance cost
- Rehabilitation cost
- Replacement cost
- Residual value.

First Cost is only one of the nine factors which influence a proper economic analysis, and 'First Cost' may be the least important factor if there are high maintenance costs or if the pipe material or system ever has to be replaced during the design life of the project.

Effective cost of an alternate material is its total cost, in today's dollars, which includes first cost, any replacement costs during the project design life, and any residual value at the end of the project design life. For each alternate material, therefore, three possible cases exist for determining effective cost:
Case 1: Material life = Project design life
Case 2: Material life < Project design life
Case 3: Material life > Project design life

When the alternate material life is equal to the project design life, its effective cost is
Simply the bid price.

$$EC = P \qquad [1]$$

where:

EC = Effective cost, dollars
P = Bid price, dollars

When the alternate material life is less than the project design life, its effective cost is the bid price plus the present value total of all replacement costs adjusted for inflation:

$$EC = P + (P \times \overline{IF} \times \overline{PVF}) \qquad [2]$$

where:

IF = inflation factor
PVF = present value factor

The inflation factor converts the current bid price to the future replacement cost:

$$IF = (1+I)^n \qquad [3]$$

where:

I = Inflation rate
n = material life, years

Once the future replacement cost is determined, it is then necessary to discount this future cost back to the present.

That is, the present value of a future cost is determined by inflating the future cost by an inflation rate and then discounting this inflated future cost to the present value by the interest as illustrated in Figure 5.

$$PVF = \left(\frac{1}{1+i}\right)^n \qquad [4]$$

where:

i = interest rate

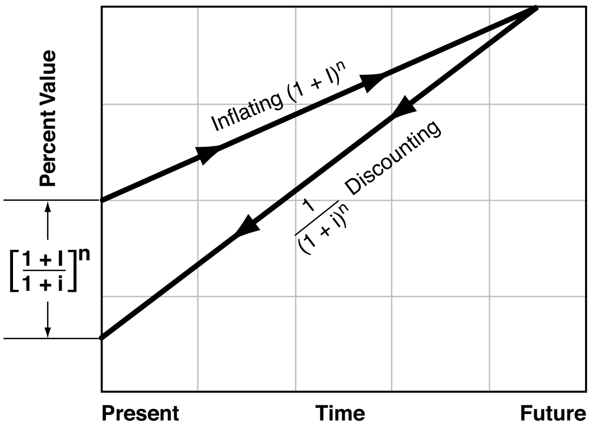
Substituting the terms for IF and PVF, the effective cost now becomes:

$$EC = P\left[(1) + \left(\frac{1+I}{1+i}\right)^n + \left(\frac{1+I}{1+i}\right)^{2n} + \left(\frac{1+I}{1+i}\right)^{mn}\right] \qquad [5]$$

where:

m = Total number of pipe replacements

Figure 1 Interest/Inflation Factor



When the alternate material life is greater than the project design life, its effective cost is the bid price minus the residual value remaining at the end of the project design life. Assuming a straight line depreciation, the effective cost of an alternate pipe material with residual value at the end of the project life is:

$$EC = P\left[(1) - \left(\frac{n-np}{n}\right)^n + \left(\frac{1+I}{1+i}\right)^{np}\right] \qquad [6]$$

where:

p = project design life, years

These forms of the equation are usable, but require assumptions to future interest and inflation rates. Calculations however, reveal that the value of the interest factor times the present value factor is virtually constant for specific differences between the two rates. Utilizing a range of inflation rates from 4 to 18 percent, and differences between the interest and inflation rates of one through five percent, the maximum , minimum, and average values are shown in Table 1. Utilizing the average values, Table 2 presents the combined inflation/interest rate factor raised to the *n* power for a number of service lives related to differences between the rates.

Use of the effective cost equation requires selection of realistic values for the various factors. Guidance on the selection of appropriate values is presented in the following section:

Proper analysis of all factors results in a pipeline which economically meets the design criteria. The difference between interest and inflation rates for projects involving state or local funding should be determined using the municipal bond rate average. Projects involving federal funding should be determined by the treasury bill rate average; and projects involving private funding should be determined by the prime lending rate.

Table 1 Inflation/Interest Rate Factor

(i - I) Percent	$\left(\frac{1+I}{1+i}\right)$		
	Maximum	Mimimum	Average
1	0.9916	0.9905	0.991
2	0.9833	0.9811	0.982
3	0.9752	0.9720	0.974
4	0.9672	0.9630	0.965
5	0.9593	0.9641	0.957

Table 2 Combined Inflation/Interest Rate Factor to n Power

$$\left(\frac{1+I}{1+i}\right)^n$$

i - I, %	n, years								
	20	25	30	40	50	60	75	80	90
1.0	0.835	0.798	0.762	0.697	0.636	0.581	0.508	0.485	0.443
2.0	0.695	0.635	0.580	0.484	0.403	0.336	0.256	0.234	0.195
3.0	0.590	0.518	0.454	0.349	0.268	0.206	0.139	0.122	0.093
4.0	0.490	0.410	0.343	0.240	0.168	0.118	0.069	0.058	0.041
5.0	0.415	0.333	0.268	0.172	0.111	0.072	0.037	0.030	0.019

The least cost of a project is the lump sum of money that would have to be set aside at one time (usually at the beginning of the project) to cover all expenditures during the entire life cycle of the project. The amount of money that must be set aside to cover future expenditure is affected by both interest rates and inflation rates. Interest may be earned on the money set aside, but inflation will increase the amount of final expenditure. Thus the effects of interest and inflation rates tend to offset each other and the net effect on life cycle cost is essentially due to the difference in these two rates.

It is not necessary to try to forecast what interest rates or inflation rates will be in the future over a 20, 50 or 100 year period because life cycle cost analysis is affected by the difference in the two rates – based on substantial historical data this difference remains relatively constant. The interest rate over a period of time will always be greater than the inflation rate, usually by 1 or 2 percentage points. Therefore, the Inflation/Interest Factor will always be less than one.

In regard to 'project design life', a review of all published culvert surveys, and current (USA) state practices published in the National Cooperative Highway Research Program Synthesis of Highway Practice titled *"Durability of Drainage Pipe"*, defines service life by the number of years of relatively maintenance-free performance. The synthesis states that a high level of maintenance may justify replacement before failure occurs. The synthesis also offers guidelines to determine required project service lives for culverts under primary and secondary highways. Based on the guide recommendations, up to 50 years of relatively maintenance-free performance should be required for culverts on secondary road facilities and up to 100 years for higher-type facilities, such as primary and interstate highways and all storm and sanitary sewers.

Once the 'project design life' is established the proven service life of the pipe material or system must be evaluated. Service life is the number of years of service a material, system or structure will provide before rehabilitation or replacement is required. Numerous culvert condition surveys dating back more than 75 years have been conducted in the United States by major, impartial specifying agencies such as the Federal Highway Administration, Soil Conservation Service, Bureau of Reclamation, Corp of Engineers and several state Departments of Transportation. Sewer condition surveys have also been conducted by local jurisdictions, municipalities, consulting engineers and universities. Project design life and service life must be established by the principal or owner.

According to the U.S. Army Corps of engineers concrete pipe has a service life of 70-100 years. Corrugated metal pipe may obtain up to a 50 year service life with the use of coatings. HDPE pipe is categorized as plastic pipe. According to the U.S. Army Corps of Engineers the designer should not expect a material service life greater then 50 years for any plastic pipe. HDPE pipes shares the same characteristics as other plastic pipes as being lightweight and flexible. Their service life greatly depends upon the installation and surrounding soil of the embankment, which will add to the initial cost of the pipe. Other factors that affect the service life of HDPE pipe include the flammability of polyethylene, and UV sensitivity.

The U.S. Army Corps of Engineers, states that the long-term performance of aluminum pipe is difficult to predict, due to a short history of use. The designer should not expect a material service life of greater than 50 years.

An extremely important report for the engineering profession is the Ohio Department of Transportation publication "*Culvert Durability Study*." Field surveys were completed and an interim report presenting the data was published in 1972. The analysis of data and recommendations are presented in the final report published in 1982. The report evaluates the durability performance of both concrete pipe and corrugated steel pipe under the same environmental conditions, and presents predictive equations and graphs for establishing service lives for both materials. The second issue of the American Concrete Pipe Association publication series, "*Buried Facts*," reviews the Ohio Report, and presents the procedures for evaluating service lives.

Figure 2 is the predictive service life graph for concrete pipe, which relates pH and pipe slope to the number of years for the pipe to reach a poor condition. In evaluating pipe, the Ohio classification system rated concrete pipe poor if there was significant loss of mortar and aggregate, and the concrete was in a softened condition. Only nine concrete culvert pipe were rated poor and they were being repaired to provide additional service. As indicated, concrete can be expected to provide a service life in excess of 100 years for all environments with a pH value above 4.0.

Figure 3 is the predictive service life graph for plain galvanized corrugated steel pipe which predicts the amount of metal loss as related to pipe age, pH of the water, and potential for abrasion. The diagonal lines, representing the pH of the water, are solid when there is potential for abrasion and dashed when there is no potential for abrasion. For design purposes, the solid lines indicating a potential for abrasion should always be used, since, in the 100 or even 50 years of required project service life, abrasion must be considered as a definite possibility.

Figure 2 Concrete Pipe Life

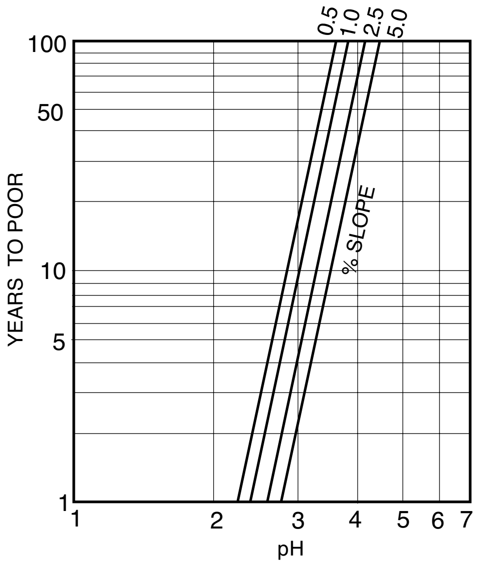
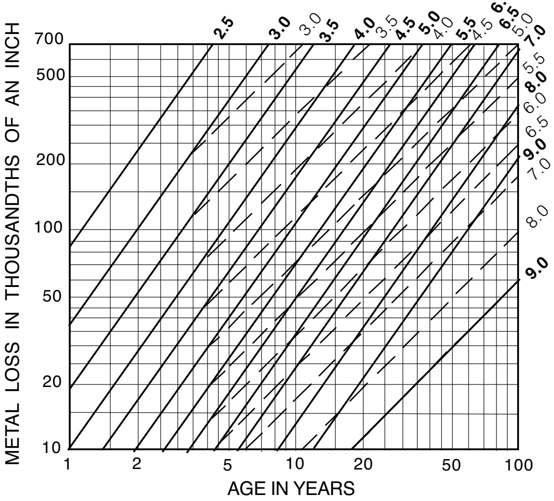


Figure 3 Predicted Metal Loss for Corrugated Metal Pipe

As an example a 16 gage (0.064" thickness) in a neutral environment with a pH=7.0 and a potential for abrasion can be expected to provide a service life of 20 years. If the pH is lowered to 4.0 the expected service life decreases to 3 years.



—— CMP WITH ABRASION $ML = 5040\ (AGE)^{1.4569}\ (pH)^{-4.4691}$

– – CMP WITHOUT ABRASION $ML = 7210\ (AGE)^{1.0164}\ (pH)^{-4.3076}$

Figures 4 and 5 are the predictive service life graphs for corrugated steel pipe with only bituminous coatings and bituminous coating with paving. The Ohio classification system considered the rating good, even if the surface of the interior coating was completely cracked throughout, some of the interior coating was gone, or the paving was eroded to the top of the corrugations. The predictive graphs, therefore, are liberal, and Ohio assigns an additional 5 to 10 year service life to bituminous coated pipe with paving, and no additional service life to only a bituminous coating. Since bituminous coating and paving have relatively short service lives, Ohio sizes all CMP based on plain corrugated pipe.

First cost is the original cost incurred in planning, designing and constructing a project including the direct cost, removal and disposal of existing materials, systems or structures, mobilization, administration, clearing and grubbing, excavation, pipe material and placement, bedding and backfilling, surface restoration, traffic maintenance, engineering and contingencies.

The actual bid prices can be used for many of the first cost items.

The effective cost of alternate materials by least cost analysis has been developed considering only the cost, adjusted for inflation, of material replacement under initial project conditions of the shorter life material or the residual value of the longer life alternate. There are many costs involved in future total replacement which are often not considered and are difficult to estimate. Among these costs are mobilization and demobilization, stream diversion, excavation, removal of the existing pipe, backfill, pavement restoration, traffic control and safety, and other incidental costs. Recently, a bid was let to replace two corrugated metal culverts with concrete pipe under an interstate highway. Although the total bid was approximately $300,000, the cost of furnishing and installing the concrete pipe was only $50,000, one sixth of the total bid. The remaining quarter million dollars was for the additional incidental costs.

Figure 4 Bitumnous Coatings

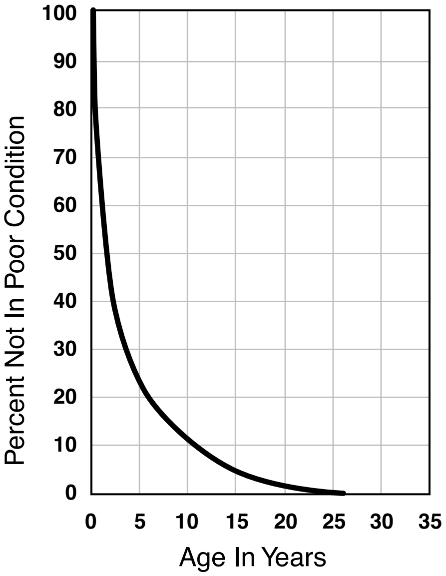
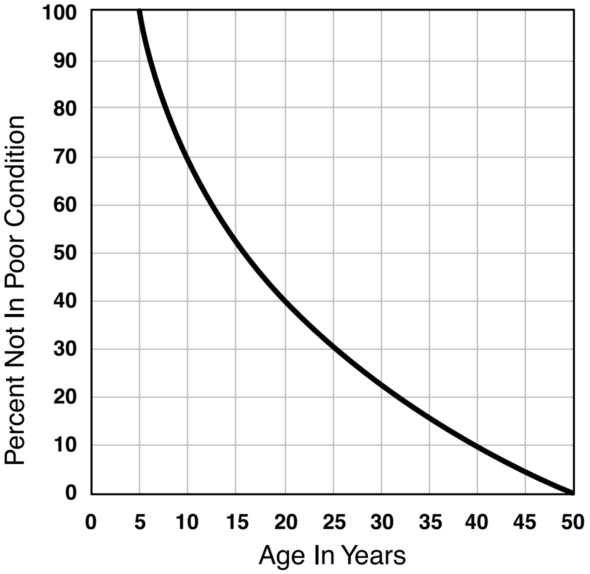


Figure 5 Bitumnous Coatings with Paving



The Inflation/Interest factor to the 'nth' power is used as a multiplier to inflate future maintenance, rehabilitation and replacement costs and then discount these future costs back to present constant dollar values. The 'n' term is the number of years in the future at which the costs are incurred. Historical data should be analyzed to determine an appropriate relationship between material cost and total project cost, and this relationship should be applied to Case 2 alternate materials to determine realistic effective costs.

If a material, system or structure has a service life greater than the project design life, it would have a residual future current dollar value, which should be discounted back to a present constant dollar value utilizing the Inflation/Interest factor and subtracted from the original cost.

A culvert is to be installed under an interstate highway with a design life of 100 years. When bids are opened, the bid price for concrete pipe was $260,000, and the bid price for bituminous coated corrugated 16 gage steel pipe was $195,000, 75 percent of the concrete price. The engineer selected a 100-year, n_c, service life for concrete pipe, and a 20-year service , n_{CSP}, for the 16 gage bituminous coated corrugated steel pipe. A difference between interest and inflation rates of 2 percent is assumed.

The effective cost of the two alternates by least cost analysis method, and select the most economical pipe material.

1. Since the service life of the concrete pipe equals the project design life, Case 1, the effective cost is found by Equation 1:

$EC_c = P_c = \$260,000$

2. Since the 16 gage steel pipe must be replaced at the end of n_{CSP}, $2n_{CSP}$, $3n_{CSP}$, and $4n_{CSP}$ years to have a total service life equal to the project design life, Case 2, the effective cost of the steel pipe is found by Equation 5:

$$EC_S=P\left[(1)+\left(\frac{1+I}{1+i}\right)^{20}+\left(\frac{1+I}{1+i}\right)^{2(20)}+\left(\frac{1+I}{1+i}\right)^{3(20)}+\left(\frac{1+I}{1+i}\right)^{4(20)}\right]$$

Substituting the steel pipe bid price and the appropriate values from Table 2 for a 2 percent difference in rates.

$EC_{CSP}=\$195,000\ (1+0.695+0.484+0.336+0.234)$

$EC_{CSP}= \$536,055$

Since the total effective cost of the 16 gage bituminous coated corrugated steel pipe is over 2 times more than the total effective cost of concrete pipe, use concrete pipe.

A culvert is to be installed under a primary road with a design life of 100 years. When bids were opened, the bid price for concrete pipe was $500,000, and the bid price for HDPE pipe $450,000. The engineer selected a 100 – year service life for concrete pipe and a maximum 50 – year service life for HDPE pipe, and stated he would compare the effective costs by the least cost analysis method, assuming a 2 percent difference between interest and inflation rates.

The effective cost of the two pipe materials.

The service life of the HDPE pipe is based on the U.S. Army Corps of Engineers guidelines.

The effective cost for the concrete pipe is equal to the bid price since it is not expected to be replaced during the project design life, Case 1. Therefore:

$EC_C = P_S = \$500,000$

However, the HDPE pipe will need to be replaced at the end of n_{HDPE}, years to have a total service life equal to the project design life, Case 2. The effective cost of the HDPE pipe is found by Equation 5:

$$P_{HDPE}\left[(1)+\left(\frac{1+I}{1+i}\right)^{50}\right]$$

Substituting in the appropriate values from Table 2 and bid price:

$EC_{HDPE} = \$450,000(1+0.403)$

$EC_{HDPE} = \$631,350$

The effective cost of the HDPE pipe, $631,350, is 26 percent more than the effective cost of the concrete pipe, therefore, use concrete pipes.

The ASTM Standard of Practice C1131 adopts a 5-step procedure:

1. Identify Objective, Alternatives and Constraints
2. Establish Basic Criteria
3. Compile Data
4. Compute LCA for each Material, System or Structure
5. Evaluate Results.

Alternatives for a road drainage system may include a pipe culvert, box culvert or a bridge. Constraints may include head and tailwater levels, maximum and minimum grades, access requirements, etc. It is important that the specific objectives be established to enable alternative means of accomplishing them to be identified. It is important to establish specific objectives so that different alternatives for accomplishing the specific objectives can be identified.

The basic criteria have been discussed earlier but should include:

- project design life
- material, system or structure service life
- first or capital cost
- maintenance, rehabilitation and replacement costs
- residual costs.

The necessary data to calculate the LCA of the proposed alternative must be collected.

Cost categories to be considered include:

- capital cost
- maintenance and operating cost
- rehabilitation or repair cost
- replacement cost

If there is a residual value at the end of the project design life, this value should be discounted back to a present value and subtracted from the original cost. The present value of all future costs is determined by multiplying each cost by the appropriate Inflation/Interest factor. As illustrated in , the Inflation/Interest factor inflates a cost into the future by an inflation rate and then discounts the inflated cost back to the present using the discount rate. Present values will always be less than future values since a present sum could be invested at the discount rate which is larger than the inflation rate. Consequently, the more distant a sum of money is to the present, the less its present value and the greater the discount rate the less a future sum of money is worth at the present.

To illustrate this concept assume a discount rate of

7% and an inflation rate of 5% for a cost to be incurred at 25 and 50 years into the future. If an object is worth \$1.00 today, with an inflation rate of 5%, it will be worth \$3.39 in 25 years and \$11.47 in 50 years.

An objective worth \$3.39 in 25 years can be discounted to a present worth of \$0.62 with a 7% discount rate. If the same object is worth \$11.47 in 50 years and has a discount rate of 7% will have a present worth value of \$0.39. The results are shown in (Figure 6).

Using the formula presented in ASTM C-1131
LCA = C - S + (M + N + R)

Where: LCA= least cost (life cycle) analysis
C = original cost
S = residual value
M = maintenance cost
N = rehabilitation cost
R = replacement cost

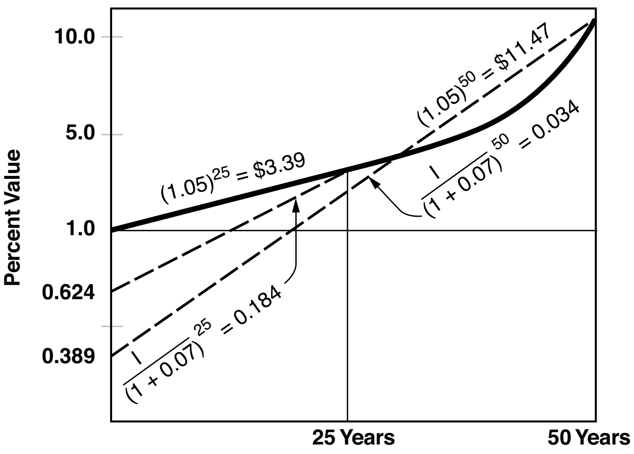
Using a straight line depreciation the residual value is further defined as:

$$S = C(F)^{n_p}\left(\frac{n_s}{n}\right)$$

Where: S = residual value
C = present constant dollar cost
n_s = number of years service life exceeds design life
n = service life
n_p = project design life
F = Inflation/Interest factor

The present value of maintenance costs can be determined by applying the Inflation/Interest factor to each cost occurrence and summing all values. If maintenance costs are established on an annual basis the following equation can be used with a nominal discount rate.

Figure 6 I = 5% i = 7%



$$M = C_m\left[\frac{1-(F)^n}{\frac{1}{F}-1}\right]$$

Where: C_m = annual maintenance cost
i = nominal discount rate
I = inflation rate
F = Inflation/Interest factor
n = service life

This example demonstrates the application of the Practice.

A 75-year design life has been assigned to a storm sewer project to be constructed for a private subdivision. Two alternative pipe with different wall thicknesses are included in the bid documents.

Material A with a project bid price of \$300,000 has been assigned a 60-year service life with an annual maintenance cost of \$6,000/year.

To meet the project design life, a \$75,000 rehabilitation cost will have to be incurred at the end of the 60-year service life.

Material B has an "in ground" cost of \$345,000 with a 100-year projected service life. The annual maintenance cost has been estimated at \$5000/year.

Planning and design costs applicable to all alternatives are \$150,000.

Based on historical data, a 5% inflation rate and 7.15% interest (discount) rate is appropriate for this project.

The most cost effective material with the lowest LCA.

Project Design Life 7 5
years ....Material A Service Life ....
60 years ....Material B Service Life ....
100 years
Inflation Rate ....5% MaterialABid
Price...................................\$300,000 MaterialBBid
Price...................................\$345,000 ....
Interest (Discount Rate).......7.15% Rehab Cost
\$75,000...............................Rehab Cost \$0.00
Inflation/Interest Factor ....1.05/1.0715=0.98 Maintenance
Cost ....\$6,000/year Maintenance
Cost \$5,000/year

To illustrate the sensitivity of the discount rate relative to the inflation rate, the discount rate will be increased from 7% to 10% in the above example, resulting in an unreasonably large difference of 5% between discount rate and inflation rate. The Inflation/Interest factor F = 1.05/1.10 = 0.9545. By increasing the discount – inflation differential from a realistic 2.15% to an artificial high 5% the LCA results are reversed such that the short service life alternate is more cost effective than the longer service life alternate. This emphasizes the importance of properly evaluating interest (discount) rates relative to inflation rates. The determination of these two rates should be based on historical data of appropriate economic indicators rather than arbitrary assumptions.

Solution: The Following Table Summarizes The Calculations and Costs

Material A	Description and Calculations	Material B
$150,000	**Planning & Design Cost**	$150,000
$300,000	**Bid Price**	$345,000
$229,390	**Maintenance Cost** $(6000)\ \frac{1-(F)^n}{\frac{1}{F}-1} = (5000)\ \frac{1-(0.98)^{75}}{\frac{1}{0.98}-1} = 38.23$	$191,158
$22,316	**Rehabilitation Cost** $(f)^n C_m = (0.98)^{60}\ 75{,}000$	0
0	**Residual Value** $C(f)^n p \left(\frac{n_s}{n}\right) = 345{,}000\ (0.98)^{75} \left(\frac{25}{100}\right)$	($18,955)
$701,706	**Total Cost**	$667,203

Answer: Material B is more cost effective since the LCA is $34,503 less than Material A.

Solution: The Following Table Summarizes The Calculations and Costs

Material A	Description and Calculations	Material B
$150,000	**Planning & Design Cost**	$150,000
$300,000	**Bid Price**	$345,000
$122,039	**Maintenance Cost** $(6000)\ \frac{1-(F)^n}{\frac{1}{F}-1} = (5000)\ \frac{1-(0.9545)^{75}}{\frac{1}{0.9545}-1} = 20.34$	$101,699
$4,588	**Rehabilitation Cost** $(f)^n C_m = (0.9545)^{60}\ 75{,}000$	0
0	**Residual Value** $C(F)^{n_p} \left(\frac{n_s}{n}\right) = 345{,}000\ (0.9545)^{75} \left(\frac{25}{100}\right)$	$2,624
$576,627	**Total Cost**	$594,075

Answer: Material A is more cost effective since the LCA is $17,448 less than Material B.