# Life-Cycle Cost for Design of Army Drainage Structures

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**Many factors are involved in the design of drainage systems. Although not necessarily overriding, the cost is often one of the most important factors. This cost should be the total, overall cost of the alternative over its projected life, or life-cycle cost. Unless the life-cycle cost is considered over first cost, the owner cannot be assured of receiving maximum value for his construction and maintenance dollars. The importance of the other decision factors are established for Army projects by the minimum functional requirements of the project. Except for determining a service life for the various types (materials) of drainage structures, the procedures for life-cycle cost analysis of such studies are well established. The procedures for economic analysis described in U.S. Army Technical Manual TM 5-802-1 can be used to determine life-cycle cost. U.S Army regulation *Economic Analysis and Program Evaluation for Resource Management* gives the basic criteria and standards for economic studies by and for the Department of the Army. Provided in this paper is the supplemental explanation required to perform life-cycle cost analyses of drainage structures to determine the relative economic rating of design alternatives. The alternatives can then be order ranked by life-cycle cost, and the best design can be rationally and confidently selected.**

Many factors are involved in the design of drainage systems. Principal factors are hydrology, soil conditions, material strength, material durability, and cost and type of facility or site being drained. Although not necessarily overriding, the cost is often one of the most important factors. This cost should be the total, overall cost of the alternative over its projected life, or life-cycle cost (LCC). Unless the LCC is considered over first cost, the owner cannot be assured of receiving maximum value for his construction and maintenance dollars. LCC-based economic studies are an integral part of the complete design process and are a requirement specified by Army Technical Manual (TM) 5-802-1(*1*). Department of the Army Regulation (AR) 11-28 *Economic Analysis and Program Evaluation for Resource Management* (*2*) gives the basic criteria and standards for economic studies by and for the Department of the Army. This paper provides the supplemental explanation required to perform LCC analyses of drainage structures to determine the relative economic rating of design alternatives.

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## GENERAL

The first step in the analysis of design alternatives is to develop a preliminary list of all possible alternatives. This list is then reduced to a group of feasible alternatives by applying the constraints of the particular project, such as availability of materials or equipment, site conditions (e.g., abrasive bed load), or requirements to accommodate large flows or livestock. In other words, the minimum functional requirements must be met. The final design is chosen from this group based on the LCC.

The LCC is the total, overall estimated cost for a particular design alternative. Direct and indirect initial costs plus periodic or continuing costs for operation and maintenance are included. The methods described in TM 5-802-1(*1*) and mentioned subsequently in this paper account for the time value of money and reflect the concepts and procedures used in many economics texts [e.g., Thuesen et al. (*3*)].

Costs incurred over time may be expressed in terms of either constant dollars or current dollars. Constant dollars are costs or savings stated at price levels in effect at some given time, usually the particular time that the analysis is conducted. Current dollars are costs or savings stated at price levels in effect whenever the costs or savings are incurred. Comparison of drainage structure alternatives should be based on constant dollars for all costs, including present and future costs and salvage or retention-residual values.

The LCC is expressed either in terms of present worth (PW) or equivalent uniform annual cost (EUAC). PW is the more common measure of LCCs. It can be thought of as the amount of money, required now, to fund the project for the entire analysis period. The EUAC can be thought of as the amount of money required for each year of the analysis period to fund all project costs.

The same analysis period must be used to compare alternatives using PWs. PWs can be converted to EUACs using a uniform series capital recovery factor. In essence, PW and EUAC are just two ways of expressing the same costs. EUACs can also be calculated from the individual costs for each alternative.

## ANALYSIS PERIOD

Economic studies consider projects that have a service life, an economic life, and an analysis period. The service life is the total useful life of the project or time to replacement or rehabilitation. The economic life is the time during which a project is economically profitable or provides the required

service at a lower cost than another facility. For drainage structures, the economic life is usually the same as the service life. The analysis period is the comparison period over which costs are counted in determining the PW or EUAC of an alternative.

The provisions of TM 5-802-1(*1*) on the selection of the analysis period are based on the fact that the Department of Defense (DOD) envisions the economic life of most types of facilities, as well as most major facilities' components and utilities, to be about 25 years for general planning purposes. This is also known as the planning horizon. Accordingly, TM 5-802-1(*1*) specifies that, in general, the analysis period should be considered to end at the end of the economic life of the total facility, or 25 years after the beneficial occupancy date (BOD), whichever occurs first. (In the case of drainage structures, the total facility would be the complete facility or set of facilities encompassing and serviced by the drainage structures.) There are provisions for exceptions to the 25-year limit, however, and it would appear that many, if not most, drainage structure projects would qualify for the exception. The justification for the exception in the case of drainage structures is that infrastructure such as drainage facilities may realistically be expected to provide economical service in its original mission well beyond 25 years. A review of the service lives used by various state and federal government agencies and industry (*4*, *5*) reveals that most agencies expect culverts to provide service longer than 25 years, with a 50-year life used most frequently. This period strikes a balance between the intangible or indirect costs associated with replacement or rehabilitation and the unpredictability of long-term land use. Accordingly, a 50-year analysis period appears to be reasonable and justifiable and should be used. Note that the selection of the analysis period is not influenced by the expected service lives of the design alternatives.

## COST

The initial and recurring costs considered in an economic analysis are sometimes categorized as agency costs, user costs, and nonuser costs (*6*). Agency costs include initial capital costs of construction; future capital costs of rehabilitation or replacement; maintenance or operational costs, or both, during the analysis period; salvage or retention-residual value (a negative cost) at the end of the analysis period; and engineering and administrative costs. User costs include travel time, vehicle operating costs, and accident costs and inconvenience (e.g., when a detour is required). Nonuser costs result from the impact of the facility on those not actually using the facility, such as the cost of flood damage occurring downstream from the drainage structure.

Economic analyses frequently include only the initial and future capital costs, maintenance and operation costs, and salvage or retention-residual value. For drainage structures, little error is introduced by omitting the other costs from the computations because the other costs are likely to be similar for all alternatives.

Initial capital costs for drainage structures can generally be estimated from local data, usually obtainable from local vendors. Future capital costs can be estimated from current costs, adjusted as necessary for extraordinary price level changes expected before future construction. As a supplement, or if local data are not available, costs can be estimated using the procedures, unit costs, and adjustment factors given in the following publications:

1. Army Regulation 415-17(*7*),
2. *Engineering News Record*'s Building and Construction Cost Index Histories (*8*),
3. Federal Highway Administration's Highway Maintenance and Operation Cost Trend Index (*9*), and
4. Federal Highway Administration's Price Trends for Federal-Aid Highway Construction (*10*).

A description of these resources and their use is included in Kohn et al.(*11*).

Maintenance and operations costs are best determined from local experience with similar projects. Maintenance and operations costs are highly dependent on both local conditions and the particular maintaining agency.

The salvage or retention-residual value of a drainage structure is its residual value at the end of the analysis period. If the end of the analysis period coincides with the end of the service of the alternative, then the salvage value of that alternative should be taken as zero. When the service life is expected to exceed the length of the analysis period, the retention-residual value must be included, generally as a future income or negative cost.

## DISCOUNT RATE

The time value of money is expressed by the discount rate. The discount rate can be viewed as the amount that the value of money in the future is reduced or discounted to reflect its present value. It is considered to be the minimum real or net rate of return, after inflation, to be achieved by public sector investments. Congress has stipulated that diverting investment capital from the private sector (by taxation) for use on public-sector projects can only be justified when that capital earns a real rate of return at least as high as that achievable in the private sector. This rate is 10 percent at the present time (January 1988) (*12*).

## COMPUTING PW

The basic method for computing the PW of a given alternative is described in detail in TM 5-802-1(*1*) and summarized here, as follows:

### One-Time Costs

Step 1: Estimate the amount of the one-time costs as of the base date (date of the study).
Step 2: Escalate this cost to the time at which it is actually to be incurred, using the differential (from inflation) escalation rate $e$.
Step 3: Discount the escalated future one-time cost to PW (on the base date), using the discount rate $d$ (10 percent in January 1988).

**Recurring Costs**

Step 1: Estimate the amount $A_o$ of the annually recurring cost as of the base date and determine the number of costs, $k$, in the series (i.e., over the analysis period).
Step 2: Escalate $A_o$ to $A_i$ at the time at which the first cost in the series is to be incurred, using the differential escalation rate $e$.
Step 3: Determine, for the date on which $A_i$ is incurred, the single cost that is equivalent to a series of, $k$, uniformly escalating annual costs, in which the amount of the first cost is $A_i$ and the differential escalation rate is $e$.
Step 4: Discount the single equivalent cost, from the time the first annual cost is to be incurred to a PW on the base date, using the discount rate $d$.

Escalation of any current cost $C$ to a future cost $F$ is accomplished using the relationship

$$F = C\,(1 + e)^n$$

where $e$ is the escalation rate above the rate of inflation and $n$ is the number of years until the future cost is incurred.

The PW $P$ of a future cost $F$ is

$$P = F\,(1/1 + i)^n$$

where $i$ is the discount or net interest rate after inflation. Formulas, tables, and sample calculations are provided in Technical Manual 5-802-1 (*1*).

## DECISION CRITERIA

If, in the judgment of the designer or analyst, it is reasonably certain from the results of the LCC analysis that one particular type of drainage structure (material) will have a lower LCC than any of the other feasible alternatives on a certain project, then that type of drainage structure should be selected for the project in question. If, on the other hand, it is clear from the results of the analysis that two (or more) of the alternatives will have equal (or very nearly equal) LCCs (and that the LCCs of all the other feasible alternatives will be greater), then the design selection should be based essentially on initial procurement cost considerations. That is, the particular type of drainage structure with the lowest procurement costs should be selected.

For other situations, when one cannot be reasonably certain from the results of the analysis whether one of the alternatives will be lower in LCC than one (or more) of the other alternatives, it may be necessary to conduct an uncertainty analysis to support the design-selection decision or to allow multiple bid options. The exact criteria are beyond the scope of this paper, but are described in detail in TM 5-802-1 (*1*).

## EXAMPLE

Suppose a drainage structure is being selected for construction 2 years after the analysis base data (date of study). The soil-water pH is 6.0, the minimum soil-water resistivity is 6,000 ohm-cm, and a nonabrasive flow of 6 ft/sec is expected. The materials to be considered are reinforced concrete, plain galvanized steel pipe, asphalt-coated and paved corrugated steel pipe (ACPCSP), and polyethylene (PE) pipe. All of these alternatives are structurally adequate for the design load. A 24-in.-diameter, smooth wall pipe will carry the design flow at the design slope of 1 percent. A 27-in.-diameter pipe will be required for the corrugated alternative because of its higher $n$ value. The differential escalation rate is projected to be 0 for installation costs and for the concrete and plain galvanized materials. For illustrative purposes, a rate of 3 percent will be assumed for the asphalt-coated and paved and PE pipes, as their cost is closely tied to the cost of petroleum. Assume that an exception will be granted to allow a 50-year analysis period, that maintenance costs over the analysis period are equal for all alternatives, and that pipe still serviceable at the end of the analysis period will not be recovered for reuse or resale (no salvage value). Uncertainty assessment is omitted for simplicity. Note that costs stated herein are hypothetical costs—they do not apply to any particular project, and are not to be used for an actual LCC analysis.

Suppose the expected service life of reinforced concrete pipe is 100 years. It should therefore last through the entire analysis period. The current cost is \$12.50/ft, delivered, plus \$10.00/ft for installation. Because $e = 0$ percent for both materials and installation, the one-time cost to be incurred in 2 years is simply \$12.50 + \$10.00 = \$22.50, in terms of today's dollars. The PW is \$22.50 $(1/1.1)^2$ = \$18.59/ft.

The California method (*13*) can be used to estimate the service life of the plain galvanized pipe. For a pH of 6.0 and a minimum resistivity of 6,000 ohm-cm, a 16-gauge, plain galvanized corrugated steel pipe (CSP) has an expected life of about 25 years. This alternative will require a replacement at the midpoint of the analysis period. The current cost of 27-in. plain galvanized pipe is \$10.65/ft, delivered, including bands, plus \$8.50/ft installation. In many cases the cost of replacement is much greater than the cost of initial construction, especially considering user costs. However, to simplify this example, assume that the current cost applies to both initial construction and replacement. Because $e = 0$ percent for both materials and installation, the cost to be incurred in 2 years and again in 27 years is \$10.65 + \$8.50 = \$19.15/ft. The PW of the initial installation is \$19.15 $(1/1.1)^2$ = \$15.82/ft. The PW of the replacement is \$19.15 $(1/1.1)^{27}$ = \$1.46/ft. The total PW for this alternative is thus \$15.82 + \$1.46 = \$17.28/ft. All these are expressed in terms of today's dollars.

Asphalt coating and paving can be used to extend the life of plain galvanized pipe. Assume that this coating will add 25 years to the life of the pipe. The service life of an asphalt-coated and paved CSP (ACPCSP) at this site will be 25 years + 25 years = 50 years, and no replacement is anticipated during the analysis period. The current cost for ACPCSP is \$13.90/ft, including bands. Assuming a 3 percent annual differential escalation rate for the cost of the asphalt, the pipe will cost \$13.90 × $(1.03)^2$ = \$14.75/ft at the time of installation. Installation is currently \$9.50/ft. Assuming $e = 0$ percent for installation cost, this cost will remain at \$9.50/ft. The total cost of this alternative will thus be \$14.75 + \$9.50 = \$24.25/ft. The PW is \$24.25$(1/1.1)^2$ = \$20.04/ft.

The proposed American Association of State Highway and Transportation Officials design procedure is structured to provide a 50-year service life. One 24-in. smooth-flow PE pipe

meeting the requirements of this procedure costs \$19.50/ft. An escalation of 3 percent for 2 years yields a cost at time of installation of \$19.50 × $(1.03)^2$ = \$20.69/ft. Installation is and will be ($e$ = 0 percent) \$8.00/ft. At the time of installation, the total cost will be \$20.69 + 8.00 = \$28.69/ft. The PW is \$28.69 × (1/1.1)2 = \$23.71/ft.

The life cycle of these alternatives is summarized in Table 1. In this example, plain galvanized CSP would be chosen for its lowest LCC. If two or three alternatives are to be selected as bid options, the CSP and RCP or CSP, RCP, and ACPCSP would be considered.

TABLE 1 EXAMPLE LIFE-CYCLE COSTS

| Cost (\$) | 24-in. RCP | 27-in. CSP 1st | 27-in. CSP 2nd | 27-in. CSP Total | 24-in. ACPCSP | 24-in. PE |
|---|---|---|---|---|---|---|
| Current material | 12.50 | 10.65 | 10.65 | | 13.90 | 19.50 |
| Installation ($e$ = 0) | 10.00 | 8.50 | 8.50 | | 9.50 | 8.00 |
| Escalated material | 12.50 | 10.65 | 10.65 | | 14.75 | 20.69 |
| PW material | 10.33 | 8.80 | 0.81 | 9.61 | 12.19 | 17.10 |
| PW installation | 8.26 | 7.02 | 0.65 | 7.67 | 7.85 | 6.61 |
| Total PW | 18.59 | | | 17.28 | 20.04 | 23.71 |

## SUMMARY

The LCC of drainage structures can be determined in accordance with the provisions of TM 5-802-1(*1*). Because of the nature of drainage structures, an analysis period greater than 25 years may be justified. However, the salvage or retention-residual value beyond the end of the analysis period is 0, except in special cases such as those where the structure will be recovered for reuse or resale. The alternatives are order ranked by LCC, and the alternative with the lowest LCC is selected. The treatment of uncertainty in the input data and the exact criteria to be used in the selection process, when the results of the LCC analysis are not conclusive, are described in detail in TM 5-802-1 (*1*).

## CONCLUSIONS

The LCC of a drainage structure design alternative is the estimated, total cost of that design. Except for determining a service life for the various types (materials) of drainage structures, the procedures for LCC cost analysis of such studies are well established. The procedures for economic analysis described in TM 5-802-1 (*1*) can be used to determine LCC. Although the LCC is only one of the decision factors used to select the preferred design alternative from among the feasible alternatives, it is generally the most important. The importance of the other decision factors are established by the minimum functional requirements of the project. The alternatives can then be order ranked by LCC, and the best design can be rationally and confidently selected.

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# DISCUSSION

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The authors have prepared an excellent summary of LCC analysis. However, there are serious errors in application. Potter and Schindler erroneously cite Office of Management and Budget (OMB) Circular *A*-94, dated March 27, 1972 (*12*), as the authority necessitating the use of a high real discount rate of 10 percent to evaluate alternate materials for a construction project. In *A*-94, the purpose is stated as follows: "This Circular prescribes a standard discount rate to be used in evaluating the measurable costs and/or benefits of programs or projects when they are distributed over time."

The scope of *A*-94 is specific on discount rate use:

**3. Scope**

*a*. This Circular applies to all agencies of the executive branch of the Federal Government except the U.S. Postal Service. The discount rate prescribed in this Circular applies to the evaluation of Government decisions concerning the initiation, renewal, or expansion of all programs or projects, other than those specifically exempted below, for which the adoption is expected to commit the Government to a series of measurable costs extending over three or more years or which result in a series of benefits that extend three or more years beyond the inception date.

*b*. Specifically exempted from the scope of this Circular are decisions concerning water resource projects (guidance for which is the approved Water Resources Principles and Standards), the Government of the District of Columbia, and non-Federal recipients of Federal loans or grants.

*c*. The remaining exemptions derive from the secondary nature of the decisions involved; that is, how to acquire assets or proceed with a program after an affirmative decision to initiate, renew, or expand such a program using this Circular. Thus:

(1) This Circular would not apply to the evaluation of decisions concerning how to obtain the use of real property, such as by lease or purchase.

(2) This Circular would not apply to the evaluation of decisions concerning the acquisition of commercial-type services by Government or contractor operation, guidance for which is OMB Circular *A*-76.

(3) This Circular would not apply to the evaluation of decisions concerning how to select automatic data processing equipment, guidance for which is OMB Circular *A*-54 and OMB Bulletin 60-6.

*d*. The discount rates prescribed in this Circular are:

(1) Suggested for use in the internal planning documents of the agencies in the executive branch;

(2) Required for use in program analyses submitted to the OMB in support of legislative and budget programs.

In other words, *A*-94 is required to be used in the evaluation of cost-benefit for projects submitted to OMB for approval to determine whether it is beneficial to finance the project with tax dollars rather than private investment. The high discount rate, then, is intended to ensure that the government does not undertake projects that can be even marginally profitable when undertaken by private investment.

After a project is approved by OMB, secondary decisions as to how to proceed with the project are exempt from the requirements of *A*-94 (i.e., the materials to be used).

The evaluation of alternate materials for a project should use realistic inflation and interest rates. There is no company that will guarantee to do a job 25 years, 50 years, or even 2 years in the future for the same price that they would charge today without a government subsidy.

Projecting long-term costs and discount rates requires evaluation of historical records. In "Taking the Guesswork Out of Least-Cost Analysis" (*1*), W. O. Kerr and B. A. Ryan examine the long-term relationships of rates and indices. Kerr and Ryan show that although wide swings occurred in interest and inflation rates, the overall average differential between the rates was relatively stable, and recommend that evaluation of construction projects be based on historical averages of the differential (real discount rate) between the producer price index and treasury bill rate for federal projects, municipal bond rate for state and local projects, and prime rate for private projects.

The future current cost and PW equations can be combined: $P = [(1 + I)/(1 + i)]^n$. Where $I$ is the inflation rate, or escalation rate defined by Potter and Schindler. Kerr and Ryan define the term $[(1 + I)/(1 + i)]$ as the interest-inflation ($i/I$) factor, which is virtually constant for any specific difference between interest and inflation rates regardless of the absolute values of the rates. Because market factors work to maintain a constant $i/I$ differential, selecting a differential and using the appropriate $i/I$ factor frees the engineer from errors related to short-term volatility of forecasts of absolute rates. Kerr and Ryan show that the average differential between treasury bill rates and the producer price index was 1.66 percent for the years 1954–1983, and the average $i/I$ factor was 0.9853. A differential of 1.66 percent is a more realistic real discount rate for evaluating construction bids by private companies on federal projects than the 10 percent used by Potter and Schindler. Recalculating the example (where RCP = reinforced concrete pipe, CSP = corrugated steel pipe, ACPCSP = asphalt-coated and paved corrugated steel pipe, PE = PE pipe, and PW = PW) using the Kerr and Ryan recommended $i/I$ factor, the results of the same costs as selected by Potter and Schindler, and an escalation factor of 0 for all costs results in:

| *Cost ($)* | *24-in. RCP* | *27-in. CSP* | *24-in. ACPCSP* | *24-in. PE* |
|---|---|---|---|---|
| PW material | 12.14 | 17.48 | 13.49 | 18.93 |
| PW installation | 9.71 | 13.95 | 9.22 | 7.77 |
| Total PW | 21.85 | 31.43 | 22.71 | 26.70 |

The cost ranking of the alternates stays the same except for CSP, which moves from lowest to highest PW. This result indicates the sensitivity of LCC analysis to the real discount rate and the importance of using a realistic differential. With a high differential, LCC analysis will always indicate that it is best to use the cheapest possible material and replace it often during the project design life.

Flexible pipe deflects, cannot carry load directly, and relies on surrounding soil to carry loads. Rigid pipe is designed to carry loads without any load transfer into surrounding soil. The more flexible a pipe, the more care, compaction, and select material is required for embedment to ensure that the surrounding soil can carry the load to prevent pipe deflections. The installation costs selected by Potter and Schindler are exactly opposite and indicate that as pipe becomes more flexible, it becomes cheaper to install.

Potter and Schindler selected the same cost for the CSP replacement as for the original installation. Pipe replacement costs are always higher than the original installation because of additional costs associated with removing the installation, traffic, safety procedures, and so on.

The California method for estimating the years to perforation of CSP is applied to the exterior and interior separately and perforation life determined by considering corrosion can proceed from both sides simultaneously. In the example, this

would reduce the service life of CSP to about 13 years. According to the Federal Highway Administration's "Evaluation of Highway Culvert Coating Performance" (*2*), six states discontinued the use of asphalt coatings because it was found to provide insufficient increase in service life to justify the cost. The long service lives selected by Potter and Schindler for CSP and asphalt-coated and paved corrugated steel pipe (ACPCSP) are questionable.

Recalculating the example with realistic service lives and costs would reorder the pipe priorities.

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## AUTHORS' CLOSURE

The discussant takes issue with the authors' use of a 10 percent real discount rate, based on the provisions of Office of Management and Budget (OMB) Circular *A*-94 (*12*), in conducting LCC analyses for design of Army drainage structures. Bealey's discussion consists in essence of three main points:

1. Materials selection for Army drainage structures is an LCC application area exempt from the provisions of OMB Circular *A*-94 (or, more simply, *A*-94), and so *A*-94 should not have been cited as the authority necessitating the use of the 10 percent discount rate;
2. The 10 percent discount rate should not have been used because its use is not mandated by *A*-94 for applications such as this (a point strongly implied, if not explicitly stated); and
3. A more realistic discount rate of 1.66 percent should have been used (instead of the 10 percent rate).

The authors take exception to all of these points, and will address each of them in turn.

Point 1. Bealey appears to have missed the point here. The authors never did, in fact, state that the LCC analysis of Army drainage structures was subject to the requirements of *A*-94, or that the 10 percent discount rate was mandated by *A*-94 for such applications. In our discussion of discount rate, we stated that "Congress has stipulated that diverting investment capital from the private sector (by taxation) for use on public sector projects can only be justified when that capital earns a real rate of return at least as high as that achievable in the private sector," and that "this rate is 10 percent at the present time," with a reference to *A*-94. That rationale is clearly valid regardless of whether or not the analysis is exempt from the provisions of *A*-94.

Point 2. We do not agree with Bealey on this point. Our position was—and remains—that the 10 percent real discount rate was the appropriate rate to use, even if its use is not mandated by *A*-94 in connection with LCC analyses for design of Army drainage structures. The basis for that position was clearly presented in the paper (although it appears that Bealey misinterpreted it). A point we did not make explicitly in the paper, but clearly should have, is that the 10 percent discount rate was the appropriate rate to use in any case. Its use is mandated by the provisions of the Army criteria documents cited in the background section of the paper—Army Regulation (AR) 11-28 (Economic Analysis and Program Evaluation for Resource Management) and Army Technical Manual (TM) 5-802-1 (Economic Studies for Military Construction Design—Applications). Although it could be argued that LCC analyses for design of Army drainage structures are exempt from the provisions of *A*-94 (as Bealey does), and perhaps even from the provisions of AR 11-28 (although this would be more difficult to argue), such analyses are certainly not exempt from the provisions of TM 5-802-1. That document establishes the governing criteria and standards for the conduct of all LCC analyses by and for the Department of the Army in connection with the design of facilities in the military construction program.

Point 3. Although we do not take issue with the fine work of Kerr and Ryan—cited by Bealey as the basis for his assertion that we should have used a real discount rate of 1.66 percent for the analysis—we do not agree that the results of the Kerr and Ryan effort are applicable here (i.e., to the conduct of LCC analyses in support of the design of Army facilities).

In conducting an LCC analysis in support of the design of an Army facility, the designer-analyst is deciding whether it would be more economical, on a total cost-of-ownership basis, to select Alternative *A*—the design alternative that is least expensive in terms of cost to purchase-construct initially—or Alternative *B*—a more expensive design alternative, which will cost less to operate, maintain, and repair over its design life. If Alternative *A* is selected (instead of Alternative *B*), the taxpayer will have to pay less taxes for the year(s) in which the facility is constructed, but will have to pay more taxes for the years that the facility is in use. If Alternative *B* is selected, the reverse will be true. It appears to us, therefore, that—on a conceptual level—the role of the government in this decision process is that of an investor of capital (on behalf of the taxpayer).

The position of the Joint Economic Committee of the Congress' Subcommittee on Economy in Government (Subcommittee on Economy in Government, 1968) is that it is the opportunity cost of displaced private spending—and not the cost to the U.S. Treasury of borrowing—that should serve as the basis for defining the discount rate to be used in public-sector economic analyses. The subcommittee states specifically in the preceding reference that "no public investment be deemed 'economic' or 'efficient' if it fails to yield overall benefits which are at least as great as those which the same resources would have produced if left in the private sector." In a classic work, Stockfisch (*1*) has shown that a real discount rate of 10 percent is the appropriate rate of return to use in this regard.

The 1.66 percent real discount rate recommended by Bealey is calculated from a nominal discount rate that is tied directly to the "treasury bill rate for federal projects" (according to Bealey) (i.e., to the government's cost of borrowing). The Subcommittee on Economy in Government specifically rejects this approach in no uncertain terms (*2*). The subcommittee states specifically in the preceding reference: "In past discussions within the Government . . . an interest rate equal to the cost to the Federal Government of borrowing has been

supported . . . Implicit in this position is the presumption that the Government is an independent organization which should seek the greatest differential between its revenues and outlays as does a private business. The subcommittee rejects this view of the Federal Government when it functions as an investor of capital."

Accordingly, in our view, the 10 percent real discount rate actually used in the analysis is the appropriate one to use, and the 1.66 percent rate urged by Bealey is not appropriate.

As for installation costs, more care, compaction, and select material is required for proper installation of flexible pipes. However, the Corps of Engineers has tailored their compaction specifications to allow the widest possible selection in, and therefore economy of, backfill material. Also, the reduced wall thickness of flexible pipes allows for smaller excavation quantities, lighter pipe sections allow use of less expensive lifting and loading equipment, and longer pipe sections result in less labor for jointing. Rigid pipe may or may not be less expensive to install than flexible pipes. The correct installation costs to use in LCC analyses are those used by local contractors to bid each alternative.

Culvert replacement can be cheaper than initial construction. Detour, delay, and resurfacing costs are insignificant for unsurfaced, tertiary roads, and labor costs may be borne by separately funded maintenance forces, not subject to contract-administration overhead.

The California method is based on actual field performance. Corrosion from both sides is therefore considered, although corrosion from the more aggressive side usually dominates the overall deterioration rate. The National Corrugated Steel Pipe Association points out that a CSP may provide satisfactory service until most of the invert is lost, which can be double the time to first perforation predicted by the California method. This results in a 50-year service life for CSP. Asphalt coating with paving, used in the example, is significantly more durable than plain asphalt coating. The authors used the 25-year coating life suggested by the American Iron and Steel Institute and others in the pipe industry. The design engineer must exercise engineering judgment in selecting design service lives, but these values are reasonable for a hypothetical example.

## REFERENCES

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