

Environmental Engineering FE CBT Exam

Knowledge: Engineering Economics with 9 Example Problems

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1 Introduction & Exam Specifications

Engineering Economics accounts for approximately 3–5 questions on the NCEES FE Environmental CBT Exam. The topics tested evaluate an engineer's capacity to perform cash flow analysis, evaluate long-term infrastructure investments, analyze capital and operational costs for environmental control systems, and compute depreciation, tax impacts, and inflation-adjusted present worth.

1.1 Key NCEES FE Exam Topics Covered

1. **Time Value of Money (TVM):** Cash flow diagrams, discrete vs. continuous compounding, single payments, uniform series, and arithmetic/geometric gradients.
2. **Equivalence & Factor Formulas:** Derivation and numerical evaluation of interest factors (P/F , F/P , P/A , A/P , F/A , A/F , F).
3. **Present Worth & Capitalized Cost Analysis:** Present Worth (PW), Future Worth (FW), Equivalent Uniform Annual Worth ($EUAW$), and Capitalized Cost (CC) for perpetual infrastructure projects.
4. **Rate of Return Analysis:** Internal Rate of Return (IRR/ROR), net present value profiling, and Incremental Rate of Return (ΔROR) analysis for mutually exclusive alternatives.
5. **Benefit-Cost Ratio (B/C) Analysis:** Conventional vs. Modified Benefit-Cost ratios, net benefit calculations, and public sector project selection guidelines.
6. **Payback Period & Breakeven Analysis:** Simple payback, discounted payback, single-variable cost-volume breakeven, and multi-alternative economic breakeven analysis.
7. **Depreciation & Tax Accounting:** Straight-Line (SL), Sum-of-Years-Digits (SYD), Declining Balance (DB/DDB), MACRS statutory tables, taxable income, and After-Tax Cash Flow ($CFAT$).
8. **Inflation & Economic Service Life (ESL):** Inflation relations (Fisher equation), constant-dollar vs. actual-dollar cash flows, and replacement analysis.

2 Time Value of Money (TVM) & Compound Interest

Money possesses a time value because capital can be invested over time to yield a positive return. The fundamental parameters in TVM calculations are:

- P : Present sum of money or present worth.
- F : Future sum of money at the end of n interest periods.
- A : End-of-period uniform annual payment or receipt in a continuous series of n equal periods.

- G : Uniform arithmetic gradient amount per period.
- g : Constant geometric growth rate per period.
- i : Interest rate per compounding period.
- n : Number of compounding periods.

2.1 Single Payment Compound Interest Formulas

For a principal amount P earning compound interest at rate i per period for n periods:

Future Amount from Present Amount (Compound Amount Factor):

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

Present Amount from Future Amount (Present Worth Factor):

$$P = F(1 + i)^{-n} = F(P/F, i, n) \quad (2)$$

Mathematical Insight: Discrete vs. Continuous Compounding

If interest is compounded m times per year at a nominal annual interest rate r , the effective interest rate per period is $i = r/m$, and the total number of periods in t years is $n = m \times t$. The future value is:

$$F = P \left(1 + \frac{r}{m} \right)^{mt} \quad (3)$$

As compounding frequency approaches infinity ($m \rightarrow \infty$), continuous compounding yields:

$$F = Pe^{rt} \implies (P/F, r, t)_{\text{continuous}} = e^{-rt} \quad (4)$$

3 Nominal vs. Effective Interest Rates

The **nominal annual rate** (r) does not account for intra-year compounding. The **effective annual rate** (i_a or i_e) reflects the actual annual yield earned or paid under compound interest.

3.1 Effective Annual Interest Rate Formulas

For m compounding periods per year at nominal annual rate r :

$$i_a = \left(1 + \frac{r}{m} \right)^m - 1 \quad (5)$$

For continuous compounding ($m \rightarrow \infty$):

$$i_a = e^r - 1 \quad (6)$$

If payments occur at a different frequency than compounding periods (e.g., monthly payments with quarterly compounding), the effective interest rate per payment period (i_{per}) must be computed:

$$i_{\text{per}} = \left(1 + \frac{r}{m} \right)^{m/k} - 1 \quad (7)$$

where k is the number of payment periods per year.

4 Uniform Series (Annuities) Factor Formulas

A uniform series consists of equal payments A occurring at the end of each period for n consecutive periods.

4.1 Uniform Series Present Worth Factor ($P/A, i, n$)

To convert a uniform series of payments A into an equivalent present worth P :

$$P = A \left[\frac{(1+i)^n - 1}{i(1+i)^n} \right] = A(P/A, i, n) \quad (8)$$

4.2 Capital Recovery Factor ($A/P, i, n$)

To determine the annual uniform payment A required to amortize a present amount P :

$$A = P \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] = P(A/P, i, n) \quad (9)$$

4.3 Uniform Series Compound Amount Factor ($F/A, i, n$)

To find the total accumulated future value F of a series of uniform end-of-period deposits A :

$$F = A \left[\frac{(1+i)^n - 1}{i} \right] = A(F/A, i, n) \quad (10)$$

4.4 Sinking Fund Factor ($A/F, i, n$)

To determine the uniform annual contribution A needed to accumulate a target future sum F :

$$A = F \left[\frac{i}{(1+i)^n - 1} \right] = F(A/F, i, n) \quad (11)$$

Summary Table of Discrete Interest Factors

Factor Name	Notation	Formula Equation	FE Handbook Relation
Single Payment Present Worth	$(P/F, i, n)$	$(1+i)^{-n}$	$P = F(P/F, i, n)$
Single Payment Compound Amount	$(F/P, i, n)$	$(1+i)^n$	$F = P(F/P, i, n)$
Uniform Series Present Worth	$(P/A, i, n)$	$\frac{(1+i)^n - 1}{i(1+i)^n}$	$P = A(P/A, i, n)$
Capital Recovery	$(A/P, i, n)$	$\frac{i(1+i)^n}{(1+i)^n - 1}$	$A = P(A/P, i, n)$
Uniform Series Compound Amount	$(F/A, i, n)$	$\frac{(1+i)^n - 1}{i}$	$F = A(F/A, i, n)$
Sinking Fund	$(A/F, i, n)$	$\frac{i}{(1+i)^n - 1}$	$A = F(A/F, i, n)$
Arithmetic Gradient Present Worth	$(P/G, i, n)$	$\frac{(1+i)^n - in - 1}{i^2(1+i)^n}$	$P = G(P/G, i, n)$
Arithmetic Gradient Uniform Series	$(A/G, i, n)$	$\frac{1}{i} - \frac{n}{(1+i)^n - 1}$	$A = G(A/G, i, n)$

5 Gradient Series Cash Flows

Gradient cash flows represent payment sequences that increase or decrease systematically over time.

5.1 Arithmetic Gradients

In an arithmetic gradient, the cash flow increases (or decreases) by a constant dollar amount G each period, beginning in period 2:

$$CF_t = A_1 + (t-1)G \quad \text{for } t = 1, 2, \dots, n \quad (12)$$

Present Worth of Arithmetic Gradient:

$$P_G = G \left[\frac{(1+i)^n - in - 1}{i(1+i)^n} \right] = G(P/G, i, n) \quad (13)$$

Equivalent Uniform Annual Series of Arithmetic Gradient:

$$A_G = G \left[\frac{1}{i} - \frac{n}{(1+i)^n - 1} \right] = G(A/G, i, n) \quad (14)$$

Total Present Worth of an arithmetic gradient series starting with base payment A_1 :

$$P_{\text{total}} = A_1(P/A, i, n) \pm G(P/G, i, n) \quad (15)$$

5.2 Geometric Gradients

In a geometric gradient, the cash flow increases (or decreases) by a constant percentage rate g per period:

$$CF_t = A_1(1+g)^{t-1} \quad \text{for } t = 1, 2, \dots, n \quad (16)$$

Present Worth of Geometric Gradient Series ($P/A, g, i, n$):

- When $i \neq g$:

$$P = A_1 \left[\frac{1 - (1+g)^n(1+i)^{-n}}{i - g} \right] = A_1 \left[\frac{1 - \left(\frac{1+g}{1+i} \right)^n}{i - g} \right] \quad (17)$$

- When $i = g$:

$$P = A_1 \left[\frac{n}{1+i} \right] \quad (18)$$

6 Present Worth Analysis & Capitalized Cost

Present worth analysis evaluates all inflows and outflows reduced to time $t = 0$ at a designated minimum attractive rate of return ($MARR$).

6.1 Equivalence Rules for Present Worth (PW)

$$PW(i) = \sum_{t=0}^n \frac{CF_t}{(1+i)^t} = \sum_{t=0}^n CF_t(P/F, i, t) \quad (19)$$

A project is economically justified if $PW(MARR) \geq 0$.

6.2 Capitalized Cost (CC)

Capitalized cost represents the present worth of an asset or infrastructure facility designed to provide service indefinitely ($n \rightarrow \infty$), such as municipal water supply dams, storm sewers, or toxic waste containment cells.

For an initial capital outlay P_0 and perpetual annual operating and maintenance cost A :

$$CC = P_0 + \frac{A}{i} \quad (20)$$

If periodic replacement costs R recur every k years indefinitely:

$$CC = P_0 + \frac{A}{i} + \frac{R}{(1+i)^k - 1} \quad (21)$$

where $\frac{R}{(1+i)^k - 1}$ is the capitalized present worth of the perpetual replacement series.

7 Equivalent Uniform Annual Worth (EUAW) Analysis

$EUAW$ converts all initial costs, annual expenses, salvage values, and periodic overhauls into an equivalent uniform annual amount over the project life cycle.

7.1 EUAW Formula

$$EUAW = -P(A/P, i, n) - A_{\text{operating}} + S(A/F, i, n) \quad (22)$$

Alternatively, using capital recovery cost (CR):

$$CR = (P - S)(A/P, i, n) + S \cdot i \quad (23)$$

$$EUAW = -CR - A_{\text{operating}} \quad (24)$$

where S is the net salvage value at year n .

Comparing Alternatives with Unequal Lives

When comparing mutually exclusive engineering alternatives with different service lives ($n_A \neq n_B$):

- **Present Worth Method:** Requires analysis over the Least Common Multiple (LCM) of their service lives, assuming identical replacement cycles.
- **EUAW Method:** Can compare directly over a single life cycle of each alternative, provided the service requirement is perpetual and identical replacements occur. This makes EUAW highly preferred for FE exam problems with unequal project lives.

8 Rate of Return (ROR / IRR) Analysis

The Internal Rate of Return (IRR) or Rate of Return (ROR) is the discount rate i^* at which the present worth of net cash inflows equals the present worth of net cash outflows:

$$PW(i^*) = \sum_{t=0}^n \frac{CF_t}{(1+i^*)^t} = 0 \quad (25)$$

8.1 Decision Criteria for Single Alternatives

- If $ROR \geq MARR$, accept the project.
- If $ROR < MARR$, reject the project.

8.2 Incremental Rate of Return Analysis (ROR)

When choosing between mutually exclusive alternatives, selecting the alternative with the highest individual ROR is mathematically invalid. Incremental analysis must be conducted:

Step-by-Step Incremental Algorithm:

1. Order alternatives by increasing initial capital investment (P_0).
2. Calculate the individual ROR for each option against the Do-Nothing baseline. Eliminate any option where $ROR < MARR$.
3. Form the incremental cash flow between the lowest-cost acceptable option (Baseline B) and the next higher-cost option (Challenger C):

$$\Delta CF_t = CF_t(C) - CF_t(B) \quad (26)$$

4. Compute the incremental rate of return ΔROR_{C-B} solving:

$$PW_{\Delta}(i^*) = 0 \quad (27)$$

5. If $\Delta ROR_{C-B} \geq MARR$, select Challenger C as the new baseline. If $\Delta ROR_{C-B} < MARR$, reject Challenger C and retain Baseline B .
6. Repeat incrementally until all alternatives have been evaluated.

9 Benefit-Cost Ratio (B/C) Analysis

Benefit-Cost ratio analysis is standard for evaluating public sector environmental infrastructure projects (flood control reservoirs, wastewater treatment plants, air quality remediation).

9.1 Definitions of Terms

- B : Present worth (or annual worth) of benefits to the public.
- D : Present worth (or annual worth) of disbenefits to the public (e.g., land loss, environmental nuisance).
- I or C_{initial} : Initial capital expenditure by the government agency.
- $O\&M$ or M : Annual operations and maintenance costs incurred by the agency.

9.2 Conventional Benefit-Cost Ratio

$$B/C = \frac{B - D}{I + O\&M} \quad (28)$$

All terms must be expressed in identical equivalent units (PW , FW , or $EUAW$).

9.3 Modified Benefit-Cost Ratio

The modified B/C ratio treats recurring $O\&M$ costs as reductions in net benefits rather than additions to government capital costs:

$$(B/C)_{\text{modified}} = \frac{B - D - O\&M}{I} \quad (29)$$

9.4 Net Benefit Criterion

$$B - C = (B - D) - (I + O\&M) \geq 0 \quad \Longleftrightarrow \quad B/C \geq 1.0 \quad (30)$$

Incremental B/C Analysis for Public Projects

For mutually exclusive public projects, rank options by initial capital cost I . Compute incremental ratio:

$$\Delta(B/C) = \frac{\Delta B - \Delta D}{\Delta I + \Delta O\&M} \quad (31)$$

If $\Delta(B/C) \geq 1.0$, the higher-cost alternative is justified.

10 Payback Period Analysis

The payback period measures the time required for accumulated revenues or savings to recover initial capital investment.

10.1 Simple (Un-discounted) Payback Period

Simple payback ignores the time value of money ($i = 0$):

$$t_{\text{payback}} = \frac{\text{Initial Capital Investment } P_0}{\text{Uniform Annual Cash Inflow } A} \quad (32)$$

If cash flows vary annually:

$$\sum_{t=1}^{t_{\text{payback}}} CF_t \geq P_0 \quad (33)$$

10.2 Discounted Payback Period

Discounted payback accounts for interest at $MARR = i$:

$$P_0 = A(P/A, i, t_{\text{discounted}}) \quad (34)$$

Solving for $t_{\text{discounted}}$:

$$t_{\text{discounted}} = -\frac{\ln\left(1 - \frac{P_0 \cdot i}{A}\right)}{\ln(1 + i)} \quad (35)$$

11 Breakeven Analysis

Breakeven analysis determines the level of an operational variable (production volume, operating hours, removal efficiency) at which two alternatives yield equal economic value.

11.1 Single Alternative Cost-Volume-Profit Breakeven

$$\text{Total Revenue } TR = p \cdot Q \quad (36)$$

$$\text{Total Cost } TC = FC + v \cdot Q \quad (37)$$

where p is unit revenue, Q is output quantity, FC is fixed cost, and v is variable cost per unit. At breakeven ($TR = TC$):

$$Q_{\text{BE}} = \frac{FC}{p - v} \quad (38)$$

11.2 Two-Alternative Economic Breakeven

Equate the total annual cost equations of Alternative 1 and Alternative 2 as a function of variable X :

$$EUAW_1(X) = EUAW_2(X) \quad (39)$$

Solve algebraically for X_{BE} .

12 Asset Depreciation & Tax Accounting

Depreciation is the non-cash deduction allowed by tax authorities to account for the physical wear and obsolescence of property used in trade or business.

12.1 Depreciation Parameters

- B_0 or C : Initial cost basis (purchase price plus shipping, installation, and site prep).
- S : Estimated salvage value at end of useful life N .
- t or k : Year of depreciation evaluation ($1 \leq t \leq N$).
- D_t : Depreciation charge in year t .
- BV_t : Book value at the end of year t ($BV_t = BV_{t-1} - D_t$).

12.2 Straight-Line (SL) Depreciation

Constant annual depreciation charge:

$$D_t = \frac{B_0 - S}{N} \quad (40)$$

$$BV_t = B_0 - t \left(\frac{B_0 - S}{N} \right) \quad (41)$$

12.3 Sum-of-Years-Digits (SYD) Depreciation

Accelerated depreciation based on the sum of years digits $SOYD = \frac{N(N+1)}{2}$:

$$D_t = \left(\frac{N - t + 1}{SOYD} \right) (B_0 - S) \quad (42)$$

12.4 Declining Balance (DB & DDB) Depreciation

Depreciation based on a fixed rate d . For Double Declining Balance (DDB), $d = 2/N$:

$$D_t = d \cdot BV_{t-1} \quad (43)$$

$$BV_t = B_0(1 - d)^t \quad (44)$$

Note: Asset cannot be depreciated below its salvage value S .

12.5 Modified Accelerated Cost Recovery System (MACRS)

MACRS is the current U.S. statutory tax depreciation system. It utilizes standardized recovery periods (3, 5, 7, 10, 15, 20 years), assumes zero salvage value ($S = 0$), and incorporates the half-year convention.

MACRS Statutory Percentage Table (Half-Year Convention)

Year (t)	3-Year Prop.	5-Year Prop.	7-Year Prop.	10-Year Prop.
1	33.33%	20.00%	14.29%	10.00%
2	44.45%	32.00%	24.49%	18.00%
3	14.81%	19.20%	17.49%	14.40%
4	7.41%	11.52%	12.49%	11.52%
5	—	11.52%	8.93%	9.22%
6	—	5.76%	8.92%	7.37%
7	—	—	8.93%	6.55%
8	—	—	4.46%	6.55%

Depreciation in year t :

$$D_t = r_t \cdot B_0 \quad (45)$$

where r_t is the MACRS percentage rate from the statutory table.

12.6 Taxation & After-Tax Cash Flow (CFAT)

$$\text{Gross Income (Revenue)} = R_t \quad (46)$$

$$\text{Taxable Income } TI_t = R_t - E_t - D_t \quad (47)$$

$$\text{Income Taxes Payable } T_t = t_e \cdot TI_t \quad (48)$$

$$CFAT_t = R_t - E_t - T_t = (R_t - E_t)(1 - t_e) + t_e \cdot D_t \quad (49)$$

where E_t is operating expense, D_t is depreciation deduction, and t_e is the effective tax rate.

13 Inflation & Real Cash Flows

Inflation reduces the purchasing power of money over time.

13.1 Fisher Inflation Equations

Let:

- i : Nominal interest rate (market rate, combined rate).
- i' : Real interest rate (inflation-free rate).
- f : Inflation rate per period.

The exact Fisher relation is:

$$1 + i = (1 + i')(1 + f) = 1 + i' + f + i'f \quad (50)$$

$$i = i' + f + i'f \quad (51)$$

$$i' = \frac{i - f}{1 + f} \quad (52)$$

13.2 Cash Flow Conversion

To calculate the Present Worth of actual (inflated) future dollars F_t using market interest rate i :

$$PW = F_t(1 + i)^{-t} = [F_t(1 + f)^{-t}] (1 + i')^{-t} \quad (53)$$

14 9 Example Problems

Example Problem 1: Deferred Uniform Series & Water Treatment Facility Expansion

Scenario: A municipal water treatment utility must perform a major upgrade on its aeration tanks. The capital cost at $t = 0$ is \$1,100,000. Operating savings resulting from high-efficiency blowers will be \$250,000 per year, beginning at the end of Year 4 and continuing through the end of Year 12 (a total of 9 equal annual savings payments). If the municipality's nominal interest rate is 8% per year compounded annually, calculate the net present worth (PW) of the project at $t = 0$.

A) \$89,450 B) \$114,320 C) \$139,750 D) \$185,210

Solution

Step 1: Identify cash flows and deferred timeline. Initial Outflow at $t = 0$: $CF_0 = -\$1,100,000$. Uniform Annual Inflow: $A = \$250,000$ for $n = 9$ years ($t = 4$ to $t = 12$). Interest rate: $i = 0.08$.

Step 2: Calculate equivalent present value of the uniform series at focal point $t = 3$.

$$(P/A, 8\%, 9) = \frac{(1.08)^9 - 1}{0.08(1.08)^9} = 6.2469 \implies P_3 = \$250,000 \times 6.2469 = \$1,561,725 \quad (54)$$

Step 3: Discount P_3 back to $t = 0$.

$$(P/F, 8\%, 3) = (1.08)^{-3} = 0.793832 \implies P_{0,\text{inflows}} = \$1,561,725 \times 0.793832 = \$1,239,747 \quad (55)$$

$$PW_{\text{net}} = \$1,239,747 - \$1,100,000 = \$139,747 \approx \$139,750 \quad (56)$$

Correct Choice: C.

Example Problem 2: Arithmetic Gradient & Industrial Landfill Maintenance Costs

Scenario: An industrial landfill post-closure monitoring program requires environmental monitoring expenses starting at \$40,000 at the end of Year 1. Due to monitoring well degradation and increasing regulatory sampling requirements, these expenses are projected to increase by \$5,000 each year through Year 8. Using an interest rate of 6% per year compounded annually, calculate the equivalent uniform annual cost ($EUAW$) over the 8-year post-closure period.

A) \$48,520 B) \$55,980 C) \$61,380 D) \$68,200

Solution

Step 1: Identify parameters. Base annual cost $A_1 = \$40,000$, $G = \$5,000$, $n = 8$, $i = 0.06$.

Step 2: Formula for $(A/G, i, n)$.

$$(A/G, 6\%, 8) = \frac{1}{0.06} - \frac{8}{(1.06)^8 - 1} = 16.6667 - 13.4714 = 3.1953 \quad (57)$$

Step 3: Compute total Equivalent Uniform Annual Worth (EUAW).

$$A_{\text{total}} = A_1 + G(A/G, 6\%, 8) = \$40,000 + \$5,000 \times 3.1953 = \$40,000 + \$15,976.50 = \$55,976.50 \approx \$55,980 \quad (58)$$

Correct Choice: B.

Example Problem 3: Continuous Compounding & Remediation Escrow Account

Scenario: A chemical manufacturing plant must deposit money into an environmental escrow fund to cover a mandatory brownfield remediation liability of \$2,500,000 due in 10 years. The escrow account earns interest at a nominal rate of 7.5% per year compounded continuously. What present lump-sum deposit must be made into the account today ($t = 0$)?

A) \$1,180,920 B) \$1,215,440 C) \$1,248,320 D) \$1,310,500

Solution

Step 1: Apply continuous compounding factor.

$$P = F \cdot e^{-rt} = \$2,500,000 \times e^{-0.075 \times 10} = \$2,500,000 \times e^{-0.75} \quad (59)$$

Step 2: Calculate Present Worth P .

$$e^{-0.75} = 0.47236655 \implies P = \$2,500,000 \times 0.47236655 = \$1,180,916.39 \approx \$1,180,920 \quad (60)$$

Correct Choice: A.

Example Problem 4: Capitalized Cost of Perpetual Municipal Water Dam

Scenario: A regional water authority is evaluating the construction of a concrete spillway for a flood control dam. Initial construction cost is \$8,500,000. Minor maintenance costs of \$120,000 occur annually. Additionally, major gate and seal overhauls costing \$600,000 are required every 15 years in perpetuity. If the interest rate is 5% per year compounded annually, calculate the Capitalized Cost (CC) of the facility.

A) \$10,900,000 B) \$11,456,100 C) \$12,185,500 D) \$13,640,000

Solution

Step 1: Capitalized cost formula.

$$CC = P_0 + \frac{A}{i} + \frac{R}{(1+i)^k - 1} \quad (61)$$

Step 2: Compute components. Initial Cost: $P_0 = \$8,500,000$. Annual Maintenance Capitalized: $\frac{\$120,000}{0.05} = \$2,400,000$. Overhaul Capitalized: $(1.05)^{15} - 1 = 1.078928 \implies \frac{\$600,000}{1.078928} = \$556,107.50$.

Step 3: Sum components.

$$CC = \$8,500,000 + \$2,400,000 + \$556,107.50 = \$11,456,107.50 \approx \$11,456,100 \quad (62)$$

Correct Choice: B.

Example Problem 5: Incremental ROR (ΔROR) Analysis for Flue Gas Scrubbers

Scenario: An industrial power plant is selecting between two air pollution control scrubbers to remove sulfur dioxide (SO_2). Both scrubbers have a 10-year useful life and zero salvage value. The plant's $MARR$ is 10% per year.

Parameter	Scrubber A (Dry)	Scrubber B (Wet)
Initial Capital Cost (P_0)	\$400,000	\$650,000
Annual Operating Cost (A)	\$70,000	\$35,000
Annual Compliance Savings	\$150,000	\$150,000
Net Annual Inflow (A_{net})	\$80,000	\$115,000

Determine the incremental rate of return (ΔROR_{B-A}) and state which scrubber should be selected.

- A) $\Delta ROR = 6.67\%$; Select Scrubber A B) $\Delta ROR = 6.67\%$; Select Scrubber B
 C) $\Delta ROR = 12.8\%$; Select Scrubber B D) $\Delta ROR = 15.1\%$; Select Scrubber B

Solution

Step 1: Form incremental cash flow. $\Delta P_0 = \$250,000$, $\Delta A = \$35,000$, $n = 10$.

Step 2: Solve for ΔROR .

$$(P/A, \Delta ROR, 10) = \frac{\$250,000}{\$35,000} = 7.1429 \quad (63)$$

Interpolating between 6% (factor 7.3601) and 8% (factor 6.7101):

$$\Delta ROR = 6\% + 2\% \times \frac{7.3601 - 7.1429}{7.3601 - 6.7101} = 6.67\% \quad (64)$$

Since $\Delta ROR = 6.67\% < MARR = 10\%$, select **Scrubber A**.

Correct Choice: A.

Example Problem 6: Conventional Benefit-Cost Ratio for Flood Mitigation

Scenario: A regional river basin authority proposes a stormwater retention dam project. Project details: $I = \$12,000,000$, $O\&M = \$350,000/\text{year}$, $B = \$1,650,000/\text{year}$, $D = \$150,000/\text{year}$, $n = 30$ years, $i = 6\%$. Calculate the Conventional Benefit-Cost Ratio (B/C).

- A) 0.92 B) 1.23 C) 1.45 D) 1.68

Solution

Step 1: Convert I to EUAW.

$$(A/P, 6\%, 30) = 0.072649 \implies A_I = \$12,000,000 \times 0.072649 = \$871,788/\text{year} \quad (65)$$

Step 2: Calculate Conventional B/C Ratio.

$$B/C = \frac{B - D}{A_I + O\&M} = \frac{\$1,650,000 - \$150,000}{\$871,788 + \$350,000} = \frac{\$1,500,000}{\$1,221,788} = 1.2277 \approx 1.23 \quad (66)$$

Correct Choice: B.

Example Problem 7: MACRS Depreciation & After-Tax Cash Flow (CFAT)

Scenario: An environmental engineering firm purchases automated water quality sampling robotics for \$180,000. Equipment falls under MACRS 5-year class ($r_2 = 32.00\%$). Year 2 revenue = \$95,000, operating expenses = \$30,000, tax rate $t_e = 25\%$. Calculate $CFAT_2$.

- A) \$48,750 B) \$58,500 C) \$63,150 D) \$72,400

Solution

Step 1: Depreciation deduction. $D_2 = \$180,000 \times 0.32 = \$57,600$.

Step 2: Taxable income and tax payable. $TI_2 = \$95,000 - \$30,000 - \$57,600 = \$7,400$. $T_2 = 0.25 \times \$7,400 = \$1,850$.

Step 3: After-Tax Cash Flow.

$$CFAT_2 = \$95,000 - \$30,000 - \$1,850 = \$63,150 \quad (67)$$

Correct Choice: C.

Example Problem 8: Cost-Volume-Profit Breakeven for Biogas Power Generation

Scenario: An anaerobic digestion facility has fixed annual costs of \$420,000/year, variable operating expenses of \$0.025/kWh, and sells electricity at \$0.085/kWh. Calculate annual production (kWh) for economic breakeven.

A) 4,941,180 kWh B) 7,000,000 kWh C) 8,400,000 kWh D) 10,500,000 kWh

Solution

$$(0.085 - 0.025) \cdot Q = 420,000 \implies 0.060 \cdot Q = 420,000 \implies Q_{BE} = 7,000,000 \text{ kWh} \quad (68)$$

Correct Choice: B.

Example Problem 9: Fisher Inflation Relation & Hazardous Waste Post-Closure Fund

Scenario: A hazardous waste facility requires \$5,000,000 in actual future dollars 15 years from now to construct a landfill cap. Inflation $f = 3.5\%$, real interest rate $i' = 4.0\%$. Calculate Present Worth (PW) required at $t = 0$.

A) \$1,657,161 B) \$1,714,800 C) \$1,780,500 D) \$1,842,100

Solution

Step 1: Calculate nominal market interest rate (i).

$$i = i' + f + i'f = 0.040 + 0.035 + (0.040 \times 0.035) = 0.0764 = 7.64\% \quad (69)$$

Step 2: Discount actual future dollars at market rate i .

$$PW = \frac{\$5,000,000}{(1.0764)^{15}} = \frac{\$5,000,000}{3.01721} = \$1,657,160.86 \quad \$1,657,161 \quad (70)$$

Correct Choice: A.