University of California, Davis
Department of Land, Air and Water Resources

Introduction to Benefit-Cost Analysis

Net Benefits = Benefit - Cost

ESM-121 Water Science and Management

Net Benefits > 0 Yes ✓
< 0 NO ☹

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$\frac{\text{Benefit}}{\text{Cost}}$ > 1 Yes ☺ ✓
< 1 No ☹ x

Presentation 3 of 20

WATER RESOURCES DEVELOPMENT

- **Need for water is becoming more acute**
- **Governments and Investors**
  - *Develop water resources*
  - *Expenditures are large*
- **Choices among alternatives should**
  - *Be efficient*
  - *Meet needs of stakeholders*
  - *Spend money wisely*

O. Eckstein,
Water Resources Development,
Harvard University Press, 1958

BENEFIT COST ANALYSIS
(COST – BENEFIT ANALYSIS)

- **Goals**
  - *Ensure that the projects use capital efficiently*
  - *Provide a framework for comparing alternative projects*
  - *Estimate the impacts of regulatory changes*

- **Basic Principle**
  - *Project benefits must exceed cost*
  - *Definition: Net Benefits = Benefits - Cost*

INTEREST RATE FORMULAS

i = interest rate

T = time in years

To Present Value

$$P = \frac{F_T}{(1+i)^T} \quad \text{...Eq. 1.1}$$

$$P = A\left[\frac{(1+i)^T - 1}{i(1+i)^T}\right] \quad \text{...Eq. 1.2}$$

To Future Value

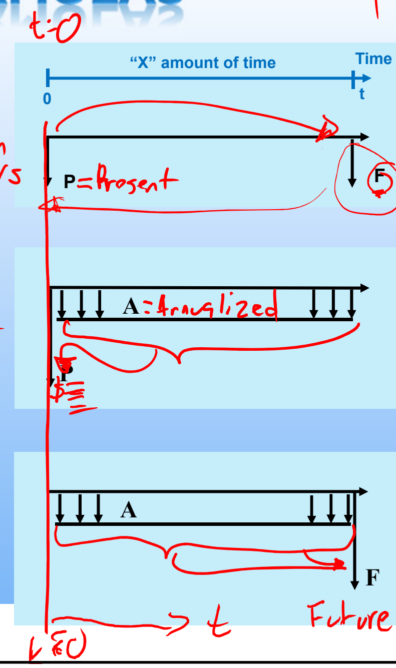
$$F_T = P(1+i)^T \quad \text{...Eq. 2.1}$$

$$F_T = A\left[\frac{(1+i)^T - 1}{i}\right] \quad \text{...Eq. 2.2}$$

To Annual Value

$$\boxed{A} = P\left[\frac{i(1+i)^T}{(1+i)^T - 1}\right] \quad \text{...Eq. 3.1}$$

$$\boxed{A} = F_T\left[\frac{i}{(1+i)^T - 1}\right] \quad \text{...Eq. 3.2}$$



INTEREST RATE FORMULAS

$100 invested for a year at an annual rate of 5% would be worth

$F_T = P(1+i)^T$

- In a year

2.1

$F_1 = \$100(1+0.05) = \$105$

$F_2 = \$105(1+0.05) = \$110.25$

- In two years

$F_2 = \$105(1+0.05) = \$110.25$

$F_3 = \$110.25(1+0.05) = 115.76$

Or, in other words (equation terms)

$F_2 = \underbrace{100(1+0.05)}_{F_1 = 105} * (1+0.05) = \$110.25$

$F_2 = 100(1+0.05)^2 = \$110.25$

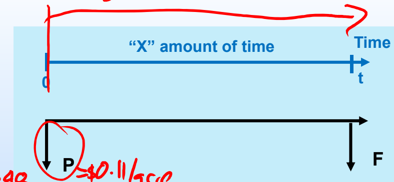
$F_T = P(1+i)^T$

$$F_T = P(1+i)^T$$ $100(1+0.05)^3 =$

TO FUTURE VALUE

$$F_t = P(1+i)^t \ldots$$ 2.1

$t = 1848$ 2013



$P = \$0.11/acre$

During the Mexican war (1848) US paid $15M for 201K sq. mi. ; ~ $0.11/acre. Article XIII. P = $0.11/acre i = 6% Interest rate per year

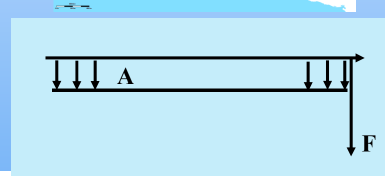
2013 − 1848

$F_{165} = \$0.11(1+0.06)^{165}$

$F_{165} = \$1{,}650/acre$

~$50K/acre Market Value

$$F_t = A\left[\frac{(1+i)^T - 1}{i}\right]$$



A = $1,000 e.g. Saving /year!!!
i = 2.5% for 10 years

$F_{10} = \$1{,}000\left[\frac{(1+0.025)^{10} - 1}{0.025}\right]$

$F_{10} = \$11{,}203$

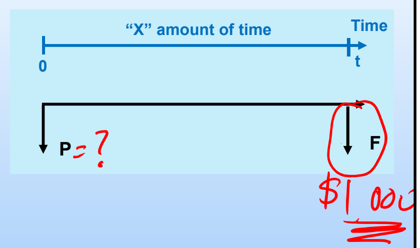
TO PRESENT VALUE

$$P = \frac{F_T}{(1+i)^T}$$

Cash $1K that will be received in the future. F = $1,000; i = 1.5% for year

$$P_1 = \frac{\$1{,}000}{(1+0.015)^1} = 985.2 \quad \text{First Year}$$

$$P_2 = \frac{\$1{,}000}{(1+0.015)^2} = 970.6 \quad \text{Second Year}$$

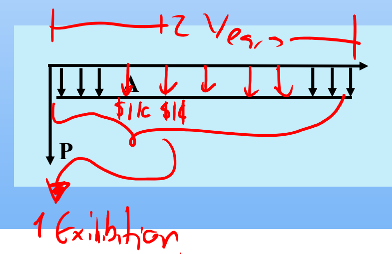


$$P = A\left[\frac{(1+i)^T - 1}{i(1+i)^T}\right]$$

A = $1,000/year, e.g. Pension
i = 1% for 12 years

$$P_{12} = \$1{,}000\left[\frac{(1+0.01)^{12} - 1}{0.01(1+0.01)^{12}}\right]$$

$$P_{12} = \$11{,}255$$



TO ANNUAL VALUE

$$A = P\left[\frac{i(1+i)^T}{(1+i)^T - 1}\right]$$

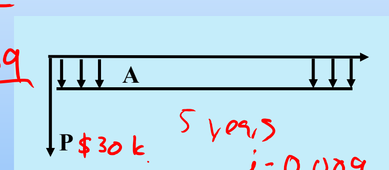
$17.5/mont.
forever $1k financed

$30K car w/APR of 0.9% for 60 months (5 years). P = $30,000; i = 0.9% for 5 years

$$A = \$30{,}000\left[\frac{0.009(1+0.009)^5}{(1+0.009)^5 - 1}\right] = \$6{,}163/12$$

$$\frac{A}{12} = \$514/month + (\$17.5 * 30) = \$1{,}039$$

$525

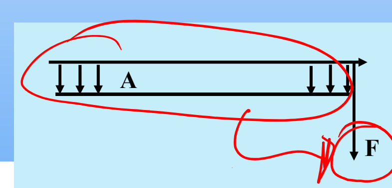


$$A = F_T\left[\frac{i}{(1+i)^T - 1}\right]$$

Delaying an investment of F = $5,000;
i = 3% for in 4 years

$$A = \$5{,}000\left[\frac{0.03}{(1+0.03)^4 - 1}\right]$$

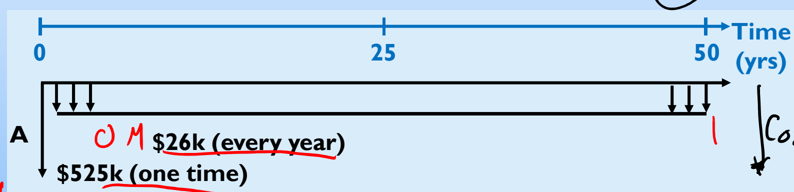
$$A = \$1{,}195$$

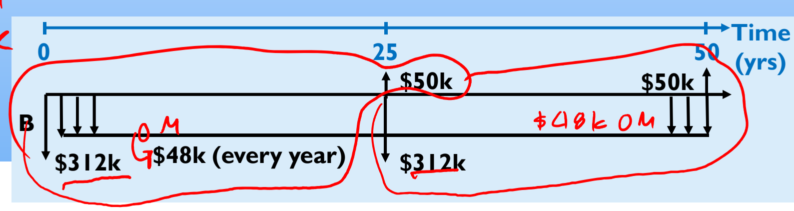


EXAMPLE PUMPING PLANT

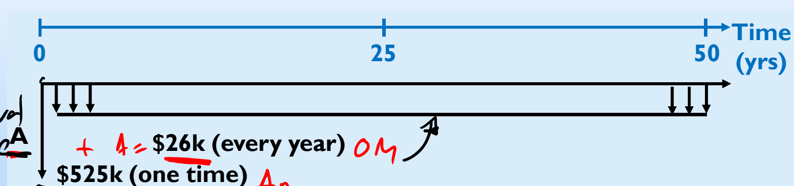
Alternative	Initial cost	Annual O&M cost	Salvage value	Life (yrs)
A	$525k	$26k	0	50
B	$312k	$48k	$50k	25

Annual value





EXAMPLE PUMPING PLANT ANNUAL COST "A"



Annual value

Capital cost

i T

$$AC_A = \$525k(Eq.\,3.1,\ 8\%, 50) + \$26k$$

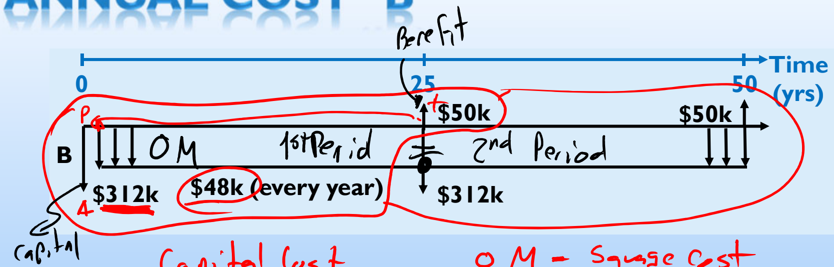
$$= \$525k\left[\frac{0.08(1+0.08)^{50}}{(1+0.08)^{50}-1}\right] + \$26k$$

$$= \$42{,}915 + \$26k \quad OM$$

$$AC_A = \$68{,}915$$

Annual cost of alternative A

EXAMPLE PUMPING PLANT ANNUAL COST "B"



Capital Cost   O M − Salvage cost

$$AC_B = \$312k(Eq.3.1,\ 8\%,25) + \$48k - \$50k(Eq.3.2, 8\%,25)$$

$$= \$312k\left[\frac{0.08(1+0.08)^{25}}{(1+0.08)^{25}-1}\right] + \$48k - \$50k\left[\frac{0.08}{(1+0.08)^{25}-1}\right]$$

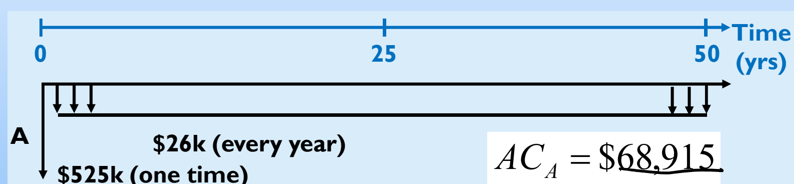
$$= \$29{,}228 + \$48k - \$684$$

$$= \$76{,}544$$

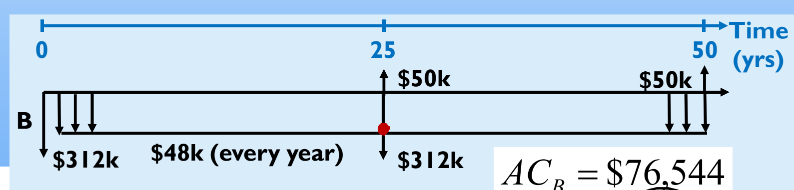
Annual cost of alternative B

EXAMPLE PUMPING PLANT

Alternative	Initial cost	Annual O&M cost	Salvage value	Life (yrs)
A	$525k	$26k	0	50
B	$312k	$48k	$50k	25

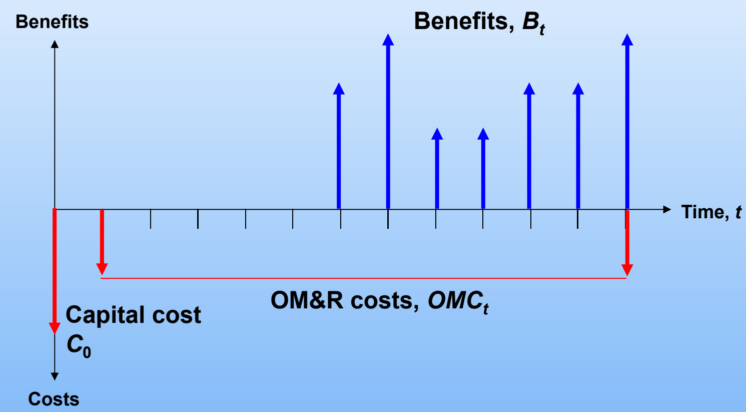


$$AC_A = \$68{,}915$$



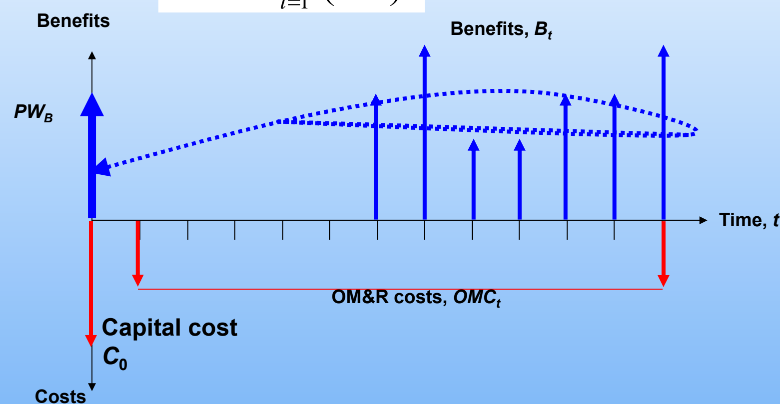
$$AC_B = \$76{,}544$$

CASH FLOW DIAGRAMS



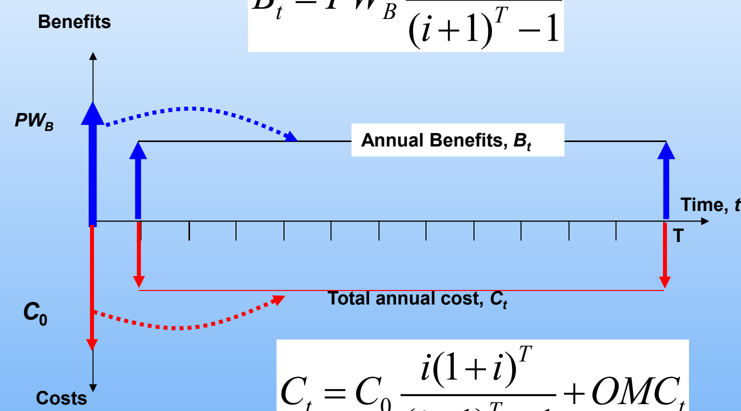
CASH FLOW DIAGRAMS

$$PW_B = \sum_{t=1}^{T} \frac{B_t}{(1+i)^t}$$



CASH FLOW DIAGRAMS

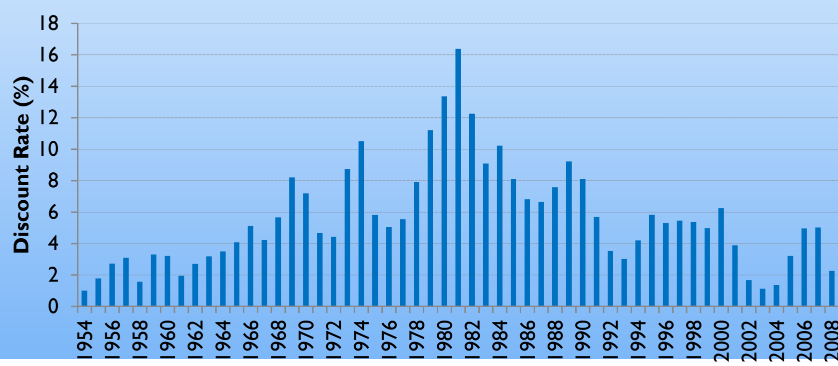
$$B_t = PW_B \frac{i(1+i)^T}{(i+1)^T - 1}$$



$$C_t = C_0 \frac{i(1+i)^T}{(i+1)^T - 1} + OMC_t$$

DISCOUNT RATE

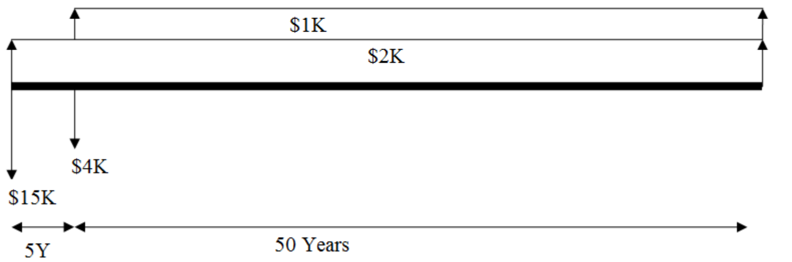
- Time value of capital used when comparing alternatives
- US federal practice (Water Resources Development Act, 1974)
  "Average rate of interest on government bonds with terms of 15 years or more"



Net Benefits Estimation: Benefit - Cost

Now, you will have to work on your own in the following exercise:

You are working with the manager of an irrigation facility who is interested in installing a more efficient pumping system. The proposed system costs \$15,000 and you estimate that it will reduce the annual utility costs by \$2,000. After five years, you expect to upgrade the system for \$4,000. This upgrade is expected to further reduce utility costs by \$1,000 annually. The annual effective interest rate is 7% and the life of the system, after upgrade is 50 years.



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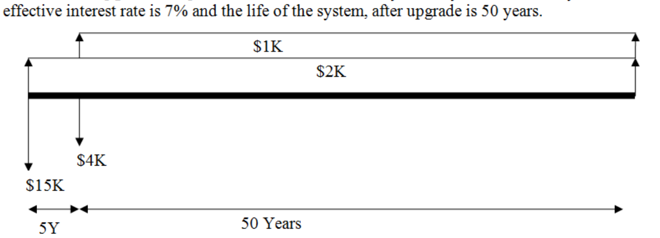


To be turned in: a) What is the Present Value of the costs (efficient pumping system and upgrade cost)? b) What is the Present Value of the benefits? c) What is the Present Value of the net benefits (benefits – costs) of the investment in the system?

BENEFIT AND COST

COSTS AND BENEFITS

- **Express in similar units (e.g. $'s)**
- **Compare for each alternative**
- **Viewpoint is important**
  - *Some groups are concerned with benefits, others with costs*
- **Compare differences between alternatives**
- **Do not consider effects on attributable to alternatives**
- **Opportunity Cost**
  - *Opportunities (net benefits) forgone in the choice of one expenditure over others*

COSTS OF ALTERNATIVES

- **Direct costs of each alternative**
  - *Capital cost*
    - *Acquisition of land and materials, construction cost*
    - *Opportunity cost (what you COULD have made)*
  - *Operation, maintenance and replacement costs*
- **Indirect cost of each alternative**
  - *Cost imposed on society or the environment*
- **Valuation techniques**
  - *Market value*
    - *Capital cost and O&M costs*
    - *Benefits from revenues from future deliveries of water*
  - *No market value? Then What?*
    - *Value = cost of cheapest alternative*
    - *Value can be estimated in other ways*

THINGS TO CONSIDER

- Investors always prefer early return on investment because the have more flexibility in making future investment decisions,
- Benefits and costs at different times should not be directly compared (they are not in common units)
- Future benefits and cost must be multiplied by a factor that becomes progressively smaller into the future (*discount rate*)
- Committing resources to one project may deny the possibility of investing in some other project. What is the *opportunity cost* or what must be forgone in order to undertake some alternatives

INCREMENTAL BENEFIT-COST METHOD

INCREMENTAL BENEFIT-COST METHOD PROCEDURE

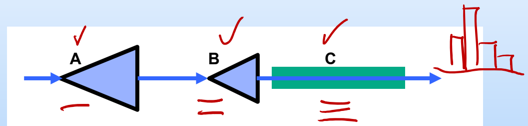
$\frac{B}{C} > 1$

1. For each alternative
   - Define consequences
   - Estimate value of consequences; i.e. Benefits (B) and Costs(C) in annualized value 3.1 or 3.2
   - Calculate B/C ratios, Discard any with B/C < 1
2. Order alternatives: Lowest to highest cost
3. Select lowest cost alternative as "Best"
   - Next higher cost alternative is "Contender"
4. Compare "Best" to "Contender"
   - Compute ΔB/ΔC, If ΔB/ΔC > 1, Contender becomes Best
5. Repeat Step 4 for all alternatives
6. Final "Current Best" is "Preferred Alternative"

$\frac{\Delta B}{\Delta C}$

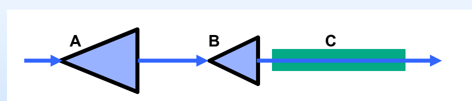
EXAMPLE

- Flood control alternatives
  - Dam A
  - Dam B, and
  - Levees C



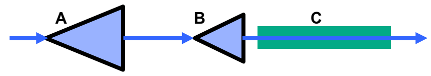
- Alternatives
  - A, B, C, AB, AC, BC, ABC
- Life expectancy
  - Dams = 80 years
  - Levee = 60 years
- Discount Rate
  - *i*= 4% per year
- Choose an alternative

STEP I



Project	Capital Cost (million $)	O&M (million $/year)	Flood Damages (million $/year)
0 Do nothing	0	0	2.0
A (dam)	6	0.09	1.1
B (dam)	5	0.08	1.3
C (levee)	6	0.10	0.7
AB	6+5 = 11	0.09+0.08 0.17	0.9
AC	6+6 12	0.09+0.10 0.19	0.4
BC	11	0.18	0.5
ABC	17	0.27	0.25

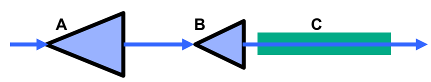
STEP 1: COST



e.g. Dam A: $A = 6\left[\frac{0.04(1+0.04)^{80}}{(1+0.04)^{80}-1}\right] = 0.251$

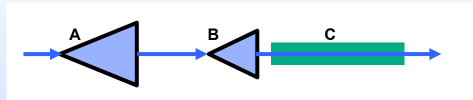
Project	Life (years)	(1) (1 = Eq. 3.1) Annual Capital Cost (mln $/year)		(2) O&M (mln $/year)		(3) (3 = 1 + 2) Costs (mln $/year)
Do nothing	i	T 0		0		0
A (dam)	80 (0.04, 80, 6)	0.251	+	0.090	=	0.341
B (dam)	80 ✓	✓ 5 0.209	+	0.080	=	0.289
C (levee)	60 (0.04, 60, 6)	0.265	+	0.100	=	0.365
AB	0.251+0.209	0.460	+	0.170	=	0.630
AC		0.516		0.190		0.706
BC		0.474		0.180		0.654
ABC		0.725		0.270		0.995

STEP 1: BENEFITS



Project	(1) Do-nothing Damages (mln $/year)		(2) Damages (mln $/year)		(3) (3 = 1 -2) Benefits (mln $/year)
Do nothing	2.0		2.0		0
A (dam)	2.0	-	1.1	=	0.9
B (dam)	2.0	-	1.3	=	0.7
C (levee)	2.0	-	0.7	=	1.3
AB	2.0	-	0.9	=	1.1
AC	2.0		0.4		1.6
BC	2.0		0.5		1.5
ABC	2.0		0.25		1.75

STEP 2



Project	Benefits (mln \$/year)	**Costs (mln \$/year)**		Rank
Do nothing	0.00	0.00	\$	1
B (dam)	0.90	0.289		2
A (dam)	0.70	0.341		3
C (levee)	1.30	0.365	\$\$	4
AB	1.10	0.630		5
BC	1.60	0.654		6
AC	1.50	0.706		7
ABC	1.75	0.995	\$\$\$\$	8

ΔB-C METHOD: STEP 3 AND 4

Compare	Project	Benef. (B) (mln\$/y)	Cost (C) (mln\$/y)	B/C	ΔB (mln\$/y)	ΔC (mln\$/y)	ΔB/ΔC	Decision
Best	Do Nothing	0	---					
θ - B					0.700	0.289	= 2.42 > 1	B > θ
Contender	B (dam)	0.700	0.289	= 2.42 > 1	0.7 - 0	0.289 - 0	Contender becomes Best	

Compute ΔB/ΔC, If ΔB/ΔC > 1, Contender becomes Best

e.g., A > B means alternative A is preferred over alternative B

ΔB-C METHOD: STEP 3 AND 4

Compare	Project	Benef. (B) (mln$/y)	Cost (C) (mln$/y)	B/C	ΔB (mln$/y)	ΔC (mln$/y)	ΔB/ΔC	Decision
	Do Nothing	---	---					
θ - B					0.700	0.289	2.42	B > θ
Best	~~B (dam)~~	~~0.700~~	~~0.289~~	2.42				
B - A					0.200	0.052	= 3.86 >1	A > B
Contender	A (dam)	0.900	0.341	= 2.64 ✓	0.9-0.7	0.341- 0.289		
	Best							

Compute ΔB/ΔC, If ΔB/ΔC > 1, Contender becomes Best

e.g., A > B means alternative A is preferred over alternative B

ΔB-C METHOD: STEP 3 AND 4

Compare	Project	Benef. (B) (mln$/y)	Cost (C) (mln$/y)	B/C	ΔB (mln$/y)	ΔC (mln$/y)	ΔB/ΔC	Decision
	Do Nothing	---	---					
θ - B					0.700	0.289	2.42	B > θ
	B (dam)	0.700	0.289	2.42				
B - A					0.200	0.052	3.86	A > B
Best	A (dam)	0.900	0.341	2.64				
A - C					0.400	0.024	= 16.44 >1	C > A
Contender	C (levee)	1.300	0.365	= 3.56 >1 ✓				

Compute ΔB/ΔC, If ΔB/ΔC > 1, Contender becomes Best

e.g., A > B means alternative A is preferred over alternative B

ΔB-C METHOD: STEP 3 AND 4

Compare	Project	Benef. (B) (mln$/y)	Cost (C) (mln$/y)	B/C	ΔB (mln$/y)	ΔC (mln$/y)	ΔB/ΔC	Decision
	Do Nothing	---	--- $					
θ - B					0.700	0.289	2.42	B > θ
	B (dam)	0.700	0.289	2.42				
B - A					0.200	0.052	3.86	A > B
	A (dam)	0.900	0.341	2.64				
A - C					0.400	0.024	16.44	C > A
Best	C (levee)	1.300	0.365	3.56				
C - AB					-0.200	0.265	-0.76 <1	C > AB
Contender	AB	1.100 /	0.630 =	1.75	1.1-1.3			
			$ $					
			$$$$					

Compute ΔB/ΔC, If ΔB/ΔC > 1, Contender becomes Best

e.g., A > B means alternative A is preferred over alternative B

ΔB-C METHOD: STEP 3 AND 4

Compare	Project	Benef. (B) (mln$/y)	Cost (C) (mln$/y)	B/C	ΔB (mln$/y)	ΔC (mln$/y)	ΔB/ΔC	Decision
	Do Nothing	---	---					
θ - B					0.700	0.289	2.42	B > θ
	B (dam)	0.700	0.289	2.42				
B - A					0.200	0.052	3.86	A > B
	A (dam)	0.900	0.341	2.64				
A - C					**0.400**	**0.024**	**16.44**	**C > A**
Best	**C (levee)**	**1.300**	**0.365**	3.56				
~~C - AB~~					~~-0.200~~	~~0.265~~	~~-0.76~~	C > AB
	~~AB~~	~~1.100~~	~~0.630~~	~~1.75~~				
C - BC					0.200 /	0.289 =	0.69 <1	C > BC
Contender	BC	1.500 /	0.654 =	2.29 ✓	1.5-1.3			

Compute ΔB/ΔC, If ΔB/ΔC > 1, Contender becomes Best

e.g., A > B means alternative A is preferred over alternative B

ΔB-C METHOD: STEP 5 AND 6

Compare	Project	Benef. (B) (mln$/y)	Cost (C) (mln$/y)	B/C	ΔB (mln$/y)	ΔC (mln$/y)	ΔB/ΔC	Decision
	Do Nothing	---	---					
θ - B					0.700	0.289	2.42	B > θ
	B (dam)	0.700	0.289	2.42				
B - A					0.200	0.052	3.86	A > B
	A (dam)	0.900	0.341	2.64				
A - C					**0.400**	**0.024**	**16.44**	**C > A**
	C (levee)	**1.300**	**0.365**	3.56				
C - AB					-0.200	0.265	-0.76 <1	C > AB
	AB	1.100	0.630	1.75				
C - BC					0.200	0.289	0.69 <1	C > BC
	BC	1.500	0.654	2.29				
C - AC					0.300	0.341	0.88 <1	C > AC
	AC	1.600	0.706	2.27				
C - ABC					0.450	0.630	0.71 <1	C > ABC
	ABC	1.750	0.995	1.76				

Compute ΔB/ΔC, If ΔB/ΔC > 1, Contender becomes Best

e.g., A > B means alternative A is preferred over alternative B

UNITS

- 1 ft = 0.3048 m
- 1 m^3 = 28.3168x10 $^{-3}$ ft^3
- 1 m^3 = 35.3147 ft^3
- 1 ha = 10,000 m^2
- 1 acre = 43,560 ft^2
  = 0.4047 ha
  = 4047 m^2
- 1 gal = 3.785x10 $^{-3}$ m^3
  = 3.785 L
- 1 m^3 = 8.11x10^{-4} af
  10^9 m^3 = 8.11x10^5 af
  1 km^3 = 0.811 maf
- 1 m^3 = 264 gal
  10^9 m^3 = 264x10^9 gal
  1 km^3 = 264 bg
  1 km^3/yr = 0.7234 bgd