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THE VALUE AND DEPRECIATION OF EXISTING FACILITIES: THE CASE OF RESERVOIRS

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Abstract:

The value of an asset is determined by the net economic value of its production over time. This value is summarized by the net present value of all present and future production. Change in asset value, depreciation or appreciation, results from both changes in the economic value of each unit of production and the asset's physical productivity. A theory of depreciation expressing this approach is derived from first principles of engineering economics. The asset's initial fabrication cost is not directly relevant to determining its net economic value once the asset exists. The theory is illustrated for the case of water resource reservoirs.

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"The simple [depreciation] methods ..., which still prevail generally in business, are analogous to the naive type of economic thought for which the only determinant of price is cost and fails to consider the equally important role played by demand." Harold Hotelling, 1925 [8]

INTRODUCTION

Recent increases in construction costs and siting difficulties have caused firms and public agencies to increasingly turn toward buying, selling, and modifying existing facilities and physical assets to serve their purposes rather than acquiring newly constructed assets. Decision-making in this environment places greater reliance on estimates of the value and depreciation of existing resources. This paper develops an engineering-economic approach to value and depreciation, extending Hotelling's [8] pioneering work on the subject. Here, value is determined by the discounted sum of benefits and costs over time and depreciation is defined as the (negative) change in an asset's value with time. This approach is not new, and has a long history in the economics [8] and accounting literatures [16]. Unfortunately, in much engineering practice this approach has been neglected in favor of simpler, but relatively arbitrary "depreciation" methods based on amortization schedules. This engineering-economic approach could be applied to many public and private facilities, and would be particularly valuable for decision-making regarding the sale of public facilities, modifications in their use, and replacement and rehabilitation decisions. The economics of new facilities is addressed extensively elsewhere [9, 10]. The engineering-economic approach to value and depreciation is illustrated for the case of government-owned reservoirs.

The economic value of a reservoir may change after it has been constructed. Sedimentation reduces its storage capacity. But, increases in the economic value of stored water raise the reservoir's value. The value of a reservoir stems only from the present and future stream of benefits and costs it produces. As time converts present benefits and costs into past benefits and costs, they become irrelevant for economic decision-making and become "sunk" costs and benefits. A machine is not valuable because it once performed well or was expensive to build, but only because it is expected to perform well in the future. Only when evaluating a potential new asset is the asset's cost germane to its valuation.

Depreciation of an asset's economic value results only from the loss of its economic productivity. This loss (or gain) has three components: 1) the loss of physical productivity, 2) the change in net economic value of a unit of production, and 3) the way in which future productivity is discounted for consideration in present value calculations. Typically, at the end of its economic lifetime an asset will produce a salvage value or disposal cost as its final product. For a reservoir, the loss of physical productivity might be the loss of storage capacity resulting from sedimentation. Changes in the value of production might result from new uses being found for stored water. The discounting of future benefits is embodied in the discount rate.

DEPRECIATION THEORY

The engineering economics approach to depreciation developed here differs from accounting approaches to depreciation. Traditionally, depreciation of capital assets serves one of two often divergent purposes: 1) to measure the decreased value of the asset and 2) to amortize, or distribute, the initial cost of the asset over its useful life [5, 6, 16, 17]. This paper defines depreciation as change in the asset's present value. Assessment of depreciation as amortization is an accounting task used to evaluate an organization's profit and loss situation or to assess an asset's initial cost to users distributed over the asset's economic lifetime [2].

The engineering (value) approach assesses asset depreciation differently, depending on what constitutes "value" to the decision-maker. To the private profit-maximizing firm, the value of an asset is perhaps best expressed as the greater of its market (sale) value or the present value of the net income the asset generates. In a competitive market, the market value represents the present value of net income the asset would generate for a potential buyer. For a firm accumulating productive assets, the marginal capital asset will have a market value (purchase cost) equal to the present value of net income generated by that marginal asset [13]. Thus, at the margin an asset's value can often be represented by its competitive market value.

A public entity may define value differently, however. A public enterprise may value not only the costs and revenues accruing to the enterprise from the asset, but may also value external benefits and costs accruing to other individuals and groups. In an era of privatization, a potential buyer would have to be willing to not only compensate the government for the present value of net asset revenues, but also cover net positive externalities that would be lost with the asset's transfer. In this case, the sale price of a public reservoir to a private interest should include the present value of any recreation or flood control externalities which would be lost because of changes in reservoir operation under private management. The loss of these externalities under private management represents a "cost" to the purposes of government (and overall economic productivity) of selling the asset to a private concern, and so should be included in the sale price of the asset. Otherwise there is no assurance that the value of the asset in private production is greater than its (net present) value in public production. Inclusion of the value of these lost externalities in the sale price compensates the government and provides some financial means to provide substitutes for these lost externalities. In any sort of public eye, the value of a resource must also include the value of its net externalities.

The measurement of depreciation as change in asset value will be affected by these varying definitions of "value." Later in this paper, a mathematical definition of depreciation is derived from the first principles of present value engineering economics, applying and somewhat modifying Hotelling's original approach [8]. These results should simplify estimation of depreciation, particularly in cases where the value of an asset at any time can be assumed to be its market value.

A few words should be said about traditional accounting approaches to depreciating the value of an asset. There are several traditional methods of depreciation based on simple mathematical functions commonly specified in income-tax legislation (straight-line, sum of years digits, double declining balance, etc.). Such functions are generally inappropriate for public facility decision-making and private decision-making outside the income-tax calculation context [2, 8]. While these accounting methods are convenient, they do not necessarily reflect the lost economic value of a facility [8, 16, 17].

Amortization methods may, in some cases, closely approximate the loss of value for some assets. For a firm or agency which has acquired many similar assets, the initial, now "sunk" cost of acquiring the marginal asset will typically approach its "value" to the firm or agency at the time of acquisition [13]. Thus, at the time of the decision to purchase the marginal asset, its price and value are roughly equal. At the end of this asset's useful life, its value is equal to its salvage value. For a short-lived asset, a linear function between these initial and final values would then likely approximate closely any engineering-economic assessment of its value and depreciation. However, for most large, long-lived, or complex assets, such simple functions may be substantially in error. Only an engineering-economic analysis can be assured of giving rigorously derived estimates of depreciation when change in asset value is of decision-making interest.

Several instances can be cited where engineering-economic and accounting-amortization approaches to depreciation can yield different solutions for important decision-making problems. In the case of the sale of an asset, its value is often estimated in practice by an amortization schedule. Since there is little reason to believe that such a schedule represents the true value of the asset in production or its market price, there is little reason to believe that the value determined from an amortization schedule is an economically efficient price, or a fair price to the seller. Since the value placed on the asset by the amortization schedule is somewhat arbitrary, it may be above or below its useful value to the present owner. (Sale of the asset is also a use.) If the amortized value is higher than its use or market value, use of the amortized value will often induce the owner not to sell when potential buyers could put the asset to a more profitable use. Similarly, a buyer assessing the value of the asset using amortization schedules will offer an excessive price for the asset if its amortized value is greater than its present value. The converse of these cases is true if the amortization schedule underestimates the useful value of the asset.

Often a government or firm must decide whether to modify its use of an asset. For governments such modifications include widening roads into adjacent parkland, changing the use of a public building from a library to a court-house, changing water supply storage from flood control to water supply uses, or adding recreation to the uses of a water supply reservoir . Applying amortization schedules to determine the value of the facility for a particular use gives little correct guidance as to whether such a modification should be made. The engineering-economic approach, however, explicitly sums, discounts, and identifies the benefits and costs of present and potential alternate uses over time, giving an appropriate basis for economic comparison of alternatives. (Environmental, social, and other comparisons may need to be performed separately.)

Scheduling maintenance and replacement of facilities using amortization schedules is another mis-application of accounting measures of depreciation. The purpose of maintenance and replacement is to maximize the net positive value of a service, including the costs of maintenance and replacement. Employing an amortization schedule to implement policies, such as renewing a facility when its amortized value becomes lower than some threshold, would seem to be foreign to a maintenance policy intended to maximize the net present value of the facility. This maximization objective is directly measured by engineering-economic approaches to depreciation and valuation, allowing explicit optimization of maintenance schedules to maximize the facility's net economic contribution [12].

Amortization approaches to depreciation may be superior to engineering-economic depreciation when change in asset value is not important for a particular decision. Many pricing or rate-making decisions require that an asset's initial "sunk" cost be assessed to present and future asset users to maintain a firm's or agency's financial solvency. The value of the asset over time is not necessarily relevant to the rate-making decision, so engineering-economic assessments of depreciation may not be appropriate here. Even traditional amortization schedules may be poor choices for rate-making decisions. Baumol derives an optimal amortization scheme that maximizes profit (or net benefits) from an asset subject to the constraint that "sunk" costs are recouped [2]. However, Baumol's results do not coincide generally with any standard amortization formula. Other illuminating discussions of optimal allocation of "sunk" costs to users also exist [3, 4]. However, amortization of fixed costs is not the subject of this paper.

This paper examines the problem of depreciation as change in value as illustrated for water resource reservoirs. The rest of this paper begins with a quantitative definition of value and derives a theory of how this value changes with time. Since present value is largely a function of future net economic productivity, the discussion then shifts to how benefits and costs vary with time. The developed theory of value and depreciation is then applied to an example illustrating the theory's implications for reservoir valuation.

ASSET VALUE OVER TIME

The economic value of an asset summarizes the value of its present and future contributions to overall economic production. This economic value is essentially forward-looking and ignores past benefits and costs as "sunk." The value of future net benefits (benefits minus costs) are discounted to account for the "opportunity cost" or interest value of having net benefits occur in the future rather than the present. The value of a asset can be summarized by the present value of its present and future production. Depreciation is then the negative change in this present value with time.

Present Economic Value

The present economic value of an asset at the end of year t is given by the series:

(1) $$V(t) = \sum_{t'=t+1}^{\infty} A(t')\ (1+i)^{-(t'-t)},$$

where A(t') is the expected annual net benefit produced by the asset in year t' assigned to the end of the year and i is the real discount rate. The real discount rate is given by:

(2) $$i = \frac{n - f}{1 + f},$$

where n is the nominal discount rate and f is the rate of inflation [16]. Utilizing the real discount rate eliminates expected inflationary effects, provided inflation affects all benefits and costs uniformly [9, 17]. Use of real discount rates eliminates the need to inflate future costs and benefits to account for the presence of inflation in the nominal discount rate. Actual real, inflation adjusted discount rates vary with time, but are more constant when averaged over long periods, averaging roughly between 2% and 4% over historical periods. Pragmatism in practice typically is held to require selection of a constant value for the real discount rate. A constant real discount rate is assumed here. For Federal reservoirs, discount rates are determined by Federal legislation. More detail on the subtleties of discount rate selection can be found in [9, 10]. The sensitivity of value and depreciation estimates to discount rate selection is discussed later.

In practice, A(t') becomes zero at the end of a project's economic lifetime and the summation in Equation 1 need only be performed between the present time t and the end of the project's economic life.

Annual Change in Present Economic Value

The annual change in an asset's value over the past year is found by subtracting its present value from its value a year ago. This is given by:

(3) $$\Delta V/\text{year} = V(t) - V(t-1).$$

Applying Equation 1, the formal derivation in Appendix A reduces this to:

(4) $$\Delta V/\text{year} = \frac{i\,V(t) - A(t)}{1 + i}.$$

Equation 4 gives the annual change in asset value over the last year. Negative values for ΔV/year constitute depreciation and positive values appreciation. The equation indicates that the rate at which asset value changes varies only with the real discount rate, its present economic value, and the value of the previous year's annual net benefits. The first term in Equation 4's numerator represents the increase in value as future net benefits come closer to actualization, just as the value of a bond increases as it approaches maturity.

The second term in Equation 4's numerator represents the annual loss of net benefits that can no longer be counted towards the asset's present value. In keeping with the forward-looking theory of value, past benefits and costs are irrelevant.

Appendix B confirms this result and offers an equivalent for Equation 4 when the value of an asset and its instantaneous rate of depreciation are required at any time during the year. Slight differences between Equations 13 and 20 arise because of differences in the definitions of A(t) for discrete and continuous cases.

The rate at which asset value changes will typically vary with time, however. It will be affected only by changes in the stream of future net benefits over time, assuming a constant real discount rate. This is examined for water resource reservoirs.

Sensitivity of Value and Depreciation Estimates to Discount Rates

Discount rates figure prominently in these estimates of value and depreciation, but accurate real discount rates are difficult to determine [9, 10]. The sensitivity of depreciation and value estimates with respect to discount rate variation is easily obtained, however. This is illustrated by an example.

An asset produces a stream of annual net benefits valued at A for each of n years. The present value of this sequence is given by:

$$V = A\frac{(1+i)^n - 1}{i(1+i)^n}. \tag{5}$$

The depreciation rate in the present year is:

$$\Delta V/\text{yr.} = -D = V_n - V_{n-1} = \frac{-A}{(1+i)^n}, \tag{6}$$

which is its sinking fund depreciation value. When discount rates and the duration of annual payments, n, are varied, present values and depreciation vary as shown in Table 1.

A somewhat more rigorous sensitivity analysis is given by the first derivative of value and depreciation with respect to the discount rate. For this case equal annual payments over a finite asset life these rates are given by:

$$\frac{dV}{di} = A\left(i^{-1}\, n\, (1+i)^{-(n+1)} - i^{-2}\, (1-(1+i)^{-n})\right) \tag{7}$$

and

$$\frac{dD}{di} = A\left(\frac{-n}{(1+i)^{n+1}}\right). \tag{8}$$

These rates of sensitivity are also shown in Table 1.

For this common case, depreciation and value are highly sensitive to selection of a discount rate. For higher discount rates, both depreciation and value become less sensitive to discount rate variation, but remain rather sensitive. For very long lived projects, $n \to \infty$, depreciation is no longer affected by discount rate variation, but value remains sensitive to discount rate variation.

These results are particular to assets generating a sequence of uniform annual payments. The sensitivity of depreciation and value estimates to discount rate selection is examined later for the more complex case of an aging reservoir later.

Table 1: Illustration of the Effects of Discount Rate Uncertainty on Present Depreciation Rate D and Asset Value V. The asset is assumed to produce an equal payment series of A lasting for n years at a real discount rate of i.

n	i	D/A	d(D/A)/di	V/A	d(V/A)/di
10	1%	0.905	-8.96	9.5	-50.81
	3%	0.744	-7.22	8.5	-43.53
	5%	0.614	-5.85	7.7	-37.50
	7%	0.508	-4.75	7.0	-32.47
20	1%	0.820	-16.23	18.0	-181.69
	3%	0.554	-10.75	14.9	-137.55
	5%	0.377	-7.18	12.5	-105.67
	7%	0.258	-4.83	10.6	-82.34
50	1%	0.608	-30.10	39.2	-909.51
	3%	0.228	-11.07	25.7	-488.55
	5%	0.087	-4.15	18.3	-282.07
	7%	0.034	-1.59	13.8	-174.49
100	1%	0.370	-36.61	63.0	-2642.37
	3%	0.052	-5.05	31.6	-884.91
	5%	0.008	-0.72	19.8	-382.47
	7%	0.001	-0.11	14.3	-202.31
∞	1%	0.000	0.00	100.0	-10,000.00
	3%	0.000	0.00	33.3	-2,500.00
	5%	0.000	0.00	20.0	-400.00
	7%	0.000	0.00	14.3	-204.08

RESERVOIR BENEFIT AND COST VARIATION OVER TIME

Equation 4 indicates that depreciation in reservoir value varies largely with changes in the expected net annual benefits produced by the reservoir, A(t). The variation of A(t) with time is thus essential for assessing actual changes in reservoir value with time.

The net annual benefits of a reservoir are found by subtracting the reservoir's annual costs from its annual benefits,

(9) $$A(t) = B(t) - C(t).$$

These values are not constant over time, nor are they certain for the future.

Benefit Variation with Time:

The function of a reservoir is generally to produce water storage. The benefits of a reservoir are then related largely to both the quantity of storage the reservoir produces and the value of the storage produced. Siltation reduces the quantity of storage produced annually by a reservoir. Increases in the economic value of stored water will raise the value of each remaining unit of storage.

The benefits of a reservoir will be the sum of all non-storage related benefits (such as perhaps a road running over the dam crest) plus the values of each unit of storage remaining in the reservoir. This is given by:

(10) $$B(t) = B_0(t) + \sum_{s=1}^{S(t)} B(s,t),$$

where $B_0(t)$ is the total annual non-storage-related benefits at time t, S(t) is the total reservoir storage remaining at time t, and B(s,t) is the economic value of the s-th unit of storage at time t. Examples of benefits which are directly related to storage are water supply for municipalities, industries, irrigation and navigation and flood control. Recreation, hydropower, and water quality control benefits are also related to storage, but less directly so. For example, when a reservoir becomes filled with sediment it retains some hydropower benefits as a run-of-river plant, but will lose much of its value to accommodate peaks in electricity demand because of the lack of storage. Assessment of values for reservoir benefits is discussed in [9, 10].

Actual reservoir benefits for any year are uncertain, depending not only on variable streamflows but also on uncertain demand for the reservoir's products. Typically, this problem is addressed by employing the expected value of benefits in each year. The determination of the expected value of each benefit for each year is beyond the scope of this paper, but has been extensively addressed elsewhere [11]. Values of B(t) and C(t) are then the expected values of reservoir benefits and costs. This expected value approach to uncertainty is generally viewed as appropriate for private assets and public assets without socially catastrophic potential [1].

Storage loss due to sedimentation reduces the value of the reservoir's annual production by the amount of storage lost times the economic value of that lost storage. For example, if 1,000 acre-ft of storage are lost in a year and the value of that storage is $100/acre-ft, the reservoir loses $100,000/year in productive value. Estimation of sedimentation rates is difficult before construction of a reservoir, when no reliable sediment trap exists. After reservoir construction, reliable sedimentation estimates can be made by surveying changes in reservoir bottom profiles.

Sediment-induced decreases in the value of annual benefits may be reduced or negated by increases in the value of remaining reservoir storage. For example, a reservoir has a storage capacity of 50,000 acre-ft where 10,000 acre-ft are initially used for municipal and industrial water supply purposes valued at $400/acre-ft and 40,000 acre-ft are initially used for flood control valued at $100/acre-ft. If urban growth results in 10,000 acre-ft of storage being switched from flood control to municipal use, the value of the reservoir's storage increases from $8,000,000/year to $11,000,000/year.

Cost Variation with Time:

The costs of reservoir operation and maintenance are not generally related to storage, but may increase with time to account for repair of structural or fixture decay.

Major rehabilitation expenses must also be considered. These expenses are of three types. A common rehabilitation expense arises from improving the reservoir facility to account for improved design standards. This is the case for rehabilitation of spillways to accommodate the larger design floods estimated by the newer probable maximum flood (PMF) standards. This type of rehabilitation expense occurs only once, and need not be repeated periodically over time. But because the facility has been upgraded to operate at a higher standard the annual benefits of having the reservoir operate at a higher standard are counted as future benefits.

The second type of rehabilitation expense are those necessary to "fix" the result of poor design, construction, or workmanship in the past. The "need" to reconstruct part of the project arises from partial failure of the facility. In this type of rehabilitation, this failure is permanently "fixed" by improved reconstruction. The benefits of these repairs merely help maintain future benefits at past levels.

The third type of rehabilitation is periodic, such as replacement of concrete surfaces which decay with time and therefore need to be replaced periodically. The same is true for dredging required to combat siltation of upstream navigation channels. These costs are periodic and will appear in the C(t) term. For structural rehabilitation their benefit lies in helping maintain future benefits. Dredging silt from channels in a reservoir's upper reaches both maintains navigation values and increases the reservoir's ability to produce storage.

Uncertainty in Future Costs and Benefits:

Despite the discussion of uncertainty above, the primary difficulty with implementing this approach to depreciation is the uncertainty inherent in estimates of future benefits and costs [14]. An insight from Equation 4 on this matter is that depreciation at any time t is a function only of the asset's present value at that time V(t) and the annual net benefits at that time A(t). Hopefully the annual value of net benefits in the present is well known, implying that the variance of A(t) is small or zero. The remaining source of uncertainty in Equation 4 is V(t), whose estimation depends on uncertain estimates of future costs, benefits, and discount rates and will often have a non-zero variance. The variance of V(t) is likely to be lower for short-lived assets or assets which have long actuarial records and specific, well-known uses. The expected value and variance of V(t) should be quite well known for common assets with competitive market values, such as used fire trucks or utility vehicles [13]. For long-lived assets the effect of uncertainty in distant benefits and costs is reduced by discounting. However, the effects of these uncertainties may be considerable [7, 15]. When considering many assets, the expected value of value and depreciation is appropriate when no socially catastrophic outcomes are possible [1]. Sensitivity analysis can examine the effects of reasonable amounts of uncertainty on value and depreciation estimates.

AN ILLUSTRATIVE EXAMPLE

A simple hypothetical reservoir illustrates the use and implications of this theory. Three cases are examined: 1) sedimentation is the only source of change over time, 2) only increases in storage value occur over time, and 3) both sedimentation and change in storage value occur.

After construction the reservoir begins with 100,000 acre-ft of storage. This storage has three uses: a) to supply municipal and industrial water, b) to provide storage for flood control, and c) to supply water for irrigation. Their initial expected values and storage allocations are given in Table 2. Other reservoir uses, where they exist, could also be incorporated. Such other uses could include hydropower generation, recreation, water quality control, or water storage for navigation. To include each use, estimates of the value of each use would have to be made for each year [10]. For particularly difficult uses, such as hydropower and recreation, forecasts of demand and the value placed on the product are difficult [9, 11]. As the reservoir fills with sediment and the economic value of storage varies, changes in the reservoir's operation are likely to be made to improve its overall productivity. The real expected costs of operating and maintaining the reservoir are assumed to be constant at $100,000/year. With no change, the reservoir produces $17 million per year in benefits and only $0.1 million in annual costs. The reservoir's value is determined assuming a constant 3% real annual discount rate.

Table 2: Annual Values of Storage

Use	Value ($/acre-ft)	Initial Storage (acre-ft)
Municipal and Industrial	$400	20,000
Flood Control	$200	20,000
Irrigation	$100	50,000
Dead (Sediment) Storage	$0	10,000

Case 1: Sedimentation Only

For this case, a sedimentation rate of 500 acre-ft per year is assumed. The trap rate is assumed to be 100% at all times. Under these conditions, the amount of storage is reduced by 500 acre-ft each year. The expected values of reservoir costs and the benefits of a unit of storage are assumed constant. For each year, the reservoir's value is shown in Figure 1 and its annual decrease in value is shown in Figure 2.

For the first 20 years siltation does not reduce the value of the reservoir's annual production, but only fills storage reserved for sedimentation. However, the reservoir's present value depreciates despite this because the time approaches when siltation will affect and eventually destroy the reservoir's productivity (Equation 4).

For the next one hundred years silt displaces the lowest-value storage and in Year 120 completely eliminates all storage for irrigation. To maximize reservoir value, storage is assumed to be continuously reallocated to the highest economic uses. The discounted value of future productivity is also reduced as the time approaches when all storage is filled with sediment.

This process continues until in Year 160 all irrigation and flood control storage is displaced and in Year 200 all storage is displaced and the reservoir's useful life has ended.

Case 2: Only Changes in the Value of Storage

This case assumes there is no sedimentation, but municipal and industrial demands grow each year, buying out or otherwise replacing flood control and irrigation storage rights. These storage rights are bought at a rate of two percent per year on the base of current municipal and industrial storage until the entire reservoir is used for municipal and industrial water supply storage. Table 3 shows how this changes the shares of storage and its annual value with time.

Note that for this case the reservoir's productivity never diminishes, since there is no sedimentation or structural deterioration. The net benefits accrue forever, but have a finite present value because of discounting. The value of the reservoir actually increases in this case until Year 75 because the annual production of the reservoir continues to increase in value.

The reservoir's value and annual change in value are shown in Figures 1 and 2. After Year 75 the reservoir's value is constant because the annual benefits used up exactly compensate for new benefits approaching the present.

Table 3: Annual Storage Allocations and Benefits for Case 2

Year	Municipal	Storage (acre-ft) Flood Control	Irrigation	Annual Value
0	20,000	20,000	50,000	$17,000,000
5	22,000	20,000	48,000	$17,600,000
10	24,400	20,000	45,600	$18,300,000
20	29,700	20,000	40,300	$19,900,000
30	36,200	20,000	33,800	$21,900,000
40	44,200	20,000	25,800	$24,300,000
50	53,800	20,000	16,200	$27,100,000
60	65,600	20,000	4,400	$30,700,000
70	80,000	10,000	0	$34,000,000
80	90,000	0	0	$36,000,000
90	90,000	0	0	$36,000,000
100	90,000	0	0	$36,000,000
200+	90,000	0	0	$36,000,000

Case 3: Both Sedimentation and Change in Storage Value

Case 3 incorporates the sedimentation rates of Case 1 and the increases in the value of reservoir storage in Case 2. The resulting annual storage allocations and benefits are shown in Table 4.

Table 4: Storage and Annual Benefit Values for Case 3

	Storage (acre-ft)			
Year	Municipal	Flood Control	Irrigation	Annual Value
0	20,000	20,000	50,000	$17,000,000
5	22,000	20,000	48,000	$17,600,000
10	24,400	20,000	45,600	$18,300,000
25	23,800	20,000	34,700	$20,600,000
50	53,800	20,000	1,200	$25,600,000
75	62,500	0	0	$25,000,000
100	50,000	0	0	$20,000,000
125	37,500	0	0	$15,000,000
150	25,000	0	0	$10,000,000
175	12,500	0	0	$5,000,000
200+	0	0	0	$0

The reservoir's value over time and its annual change in value are shown in Figures 1 and 2.

Here, even the rapid rise in the value of storage cannot postpone the year when sedimentation occupies the reservoir's entire productive capacity. However, in the short run, the increasing value of reservoir storage raises both the annual value of reservoir production and the reservoir's present value.

For this case, the value of the reservoir is almost always between that of Cases 1 and 2. However, towards the end of the reservoir's economic life, when all remaining storage is devoted to the highest value use, the reservoir's value in this case is identical to that in the siltation-only case.

For a reservoir which is relatively young relative to its economic lifetime, such as most reservoirs in the United States, it is quite likely for the reservoir to be increasing in value, as is the case here. Where new uses for stored water, such as recreation, compound the value of stored water, the rise could be much greater than in the illustration. In the long run, however, the effects of sedimentation ultimately eliminate the reservoir's economic productivity and value. Figures 1 and 2 also illustrate that value and depreciation for reservoirs is also unlikely to follow a simple amortization function. Moreover, these value and depreciation estimates are not functions of the initial cost of the reservoir.

Discount Rate Sensitivity

Figures 3 and 4 show the estimates of reservoir value and depreciation for Case 3 (both sedimentation and change in storage value) under three different discount rate assumptions, 2%, 3%, and 4%. These changes in discount rate have a considerable effect on estimates of value and depreciation over time. However, as the reservoir approaches the end of its useful life, these values tend to converge on zero. For estimates of value, the difference between the estimates diminishes steadily over time. For depreciation estimates, they diverge from initially close estimates and later converge again towards the end of the reservoir's useful life.

CONCLUSIONS

This paper derives and applies an engineering economic definition of value and depreciation. This definition is an elaboration of the traditional engineering economic approach to depreciation [5, 6, 8, 16, 17].

This engineering approach has advantages over accounting approaches to depreciation in that it is theoretically derivable from first principles of economics, asset productivity, and the economic value of asset production. Only this type of approach will rigorously measure loss of asset value over time. However, these assessments of depreciation and value are uncertain, due to uncertainty in future benefits, costs, and discount rates. Assessment of asset value is required for making correct sale, purchase, rehabilitation, maintenance, and other decisions which attempt to maximize the economic value of an asset's employment. New investments differ in having no "sunk" costs. This engineering approach to depreciation is not necessarily appropriate for allocating "sunk" costs to asset users through pricing or rate-making [2, 3, 4].

Engineering-economic depreciation analysis is often less convenient than traditional accounting methods. For very small facilities the analysis required to conduct an engineering depreciation analysis may be unwarranted. But it is expected that most large or long-lived facilities (including reservoirs) depreciate at irregular rates over time and are of sufficient economic importance that they merit a more detailed analysis, including explicit consideration of uncertainty.

Several causes of change in reservoir value have been identified. Perhaps the most important of these are sedimentation and changes in the economic value of reservoir storage. Changes in operating and maintenance costs may also be important. Sedimentation always depreciates the present value of a reservoir, but changes in the economic value of reservoir storage may either depreciate or increase the present economic value of a reservoir. Where there is no change in reservoir storage, constant costs for operating and maintaining that storage, and constant values for each unit of reservoir storage, there is neither depreciation nor appreciation in value.

This approach to estimating depreciation and some of the derived expressions for depreciation should be useful for depreciation studies where change in value is of decision-making importance. As the economics of new construction has become less favorable for many public agencies, increasing consideration should be devoted to the economics of maintaining, rehabilitating, replacing, modifying, purchasing, and selling existing facilities. The value and depreciation estimation methods developed here may be useful in this context.

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REFERENCES

[1] Arrow, K. J. and R.C. Lind (1970), "Uncertainty and the Evaluation of Public Investment Decisions," American Economic Review, Vol. 60, pp. 364-378.

[2] Baumol, William J. (1971), "Optimal depreciation policy: pricing the products of durable assets," Bell Journal of Economics and Management Science, Vol. 2, No. 2 (Autumn), pp. 638-656.

[3] Driessen, T.S.H. and S.H. Tijs (1985), "The Cost Gap Method and Other Allocation Methods for Multipurpose Water Projects," Water Resources Research, Vol. 21, No. 10, October, pp. 1469-1475.

[4] Giglio, Richard J. and Robert Wrightington (1972), "Methods for Apportionning Costs Among Participants in Regional Systems," Water Resources Research, Vol. 8, No. 5, October, pp. 1133-1144.

[5] Grant, Eugene L. and W. Grant Ireson (1982), Principles of Engineering Economy, Wiley, N.Y., 574 pp.

[6] Grant, Eugene L. and Paul T. Norton (1955), Depreciation, The Ronald Press Company, New York.

[7] Hanke, Steve H. and Richard A. Walker (1974), "Benefit-Cost Analysis Reconsidered: An Evaluation of the Mid-State Project," Water Resources Research, Vol. 10, No. 5, pp. 898-908.

[8] Hotelling, Harold (1925), "A General Mathematical Theory of Depreciation," Journal of the American Statistical Association, Vol. 20, No. 151, September, pp. 340-353.

[9] Howe, Charles W. (1971), Benefit-Cost Analysis for Water Systems, American Geophysical Union, Water Resources Monograph No. 2, Washington, DC, 144 pp.

[10] James, L. Douglas and Robert R. Lee (1971), Economics of Water Resources Planning, McGraw-Hill Book co., N.Y., 615 pp.

[11] Loucks, Daniel P., Jery R. Stedinger, and Douglas A. Haith (1981), Water Resource Systems Planning and Analysis, Prentice-Hall, Inc., Englewood Cliffs, NJ, 559 pp.

[12] Lund, Jay R. (1988), "Metering Utility Services: Evaluation and Maintenance," Water Resources Research, Vol. 24, No. 6, June, pp. 802-816.

[13] Mansfield, Edwin (1975), Microeconomics: Theory and Applications, W.W. Norton and Co., Inc., N.Y., 534 pp.

[14] Nellis, Richard E. (1985), "A Note on the Meaning, Theory, and Common Sense of Depreciation - "Economic" or Otherwise," Public Utility Fortnightly, Vol. 116, 17 October, pp. 53-54.

[15] Palanisami, K. and K. William Easter (1984), "Ex Post Evaluation of Flood Control Investments: A Case Study in North Dakota," Water Resources Research, Vol. 20, No. 12, December, pp. 1785-1790.

[16] Saliers, Earl A. (1916), Principles of Depreciation, The Ronald Press Company, New York.

[17] Thuesen, G.J. and W.J. Fabrycky (1984), Engineering Economy, Prentice-Hall, Englewood Cliffs, NJ, 633 pp.

APPENDIX A - DERIVATION OF ENGINEERING-ECONOMIC DEPRECIATION

The value of an asset at the end of year t is the discounted sum of the net benefits it produces in the future. This is given by:

$$(11) \qquad V(t) = \sum_{t'=t+1}^{\infty} A(t')\,(1+i)^{-(t'-t)},$$

where i is the real annual discount rate and A(t') is the net benefit produced by the reservoir in year t' and assigned to the end of year t'.

The change in asset value during the last year t is the value it has at the year's end minus its value at the year's beginning (last year's end). This is given by:

$$(12) \qquad \Delta V/\text{year} = V(t) - V(t-1).$$

Substituting Equation 11 into Equation 12 yields:

$$(13) \qquad \Delta V/\text{yr} = \sum_{t'=t+1}^{\infty} A(t')(1+i)^{-(t'-t)} - \sum_{t'=t}^{\infty} A(t')(1+i)^{-(t'-t+1)}.$$

By shifting the limits of summation, Equation 13 can be equivalently expressed as:

$$(14) \qquad \Delta V/\text{yr} = \sum_{t'=t+1}^{\infty} A(t') \left[(1+i)^{-(t'-t)} - (1+i)^{-(t'-t+1)}\right] - A(t)\,(1+i)^{-1}.$$

Equation 14 is simplified to:

$$(15) \qquad \Delta V/\text{yr} = \sum_{t'=t+1}^{\infty} A(t') \left[(1+i)^{-(t'-t)}\right] \left[1 - (1+i)^{-1}\right] - A(t)\,(1+i)^{-1}$$

Applying Equation 11 reduces Equation 15 to:

$$(16) \qquad \Delta V/\text{yr} = V(t)\left[1 - (1+i)^{-1}\right] - A(t)\,(1+i)^{-1},$$

which can be further simplified to our final result for the change in asset value over the last year:

$$(17) \qquad \Delta V/\text{yr} = \frac{i\,V(t) - A(t)}{(1+i)}.$$

Since depreciation is the negative of the change in asset value in time, $D(t) = -\Delta V(t)/\text{year}$,

$$(18) \qquad D(t) = \frac{A(t) - i\,V(t)}{(1+i)}.$$

A continuous formulation and solution of this problem appears in Appendix B with similar results.

APPENDIX B - A CONTINUOUS DERIVATION OF ENGINEERING-ECONOMIC DEPRECIATION

The value of any asset at any instant of time t is given by the integral of its discounted net benefits into the indefinite future [8]. Assuming a constant real continuous discount rate r, this becomes:

$$(19) \qquad V(t) = \int_t^{\infty} A(\tau)\, e^{-r(\tau - t)}\, d\tau$$

or

$$(20) \qquad V(t) = e^{rt} \int_t^{\infty} A(\tau)\, e^{-r\tau}\, d\tau$$

where $A(\tau)$ is the expected value of net benefits at time τ and $r = \ln(1 + i)$, where i is the real annual discount rate [8].

The rate of change in asset value with time is then,

$$(21) \qquad \frac{dV(t)}{dt} = r\, e^{rt} \int_t^{\infty} A(\tau)\, e^{-r\tau}\, d\tau \ - \ A(t)\, e^{-rt}\, e^{rt}.$$

This simplifies to:

$$(22) \qquad \frac{dV(t)}{dt} = r \int_t^{\infty} A(\tau)\, e^{-r(\tau - t)}\, d\tau \ - \ A(t),$$

and substituting in Equation 19,

$$(23) \qquad \frac{dV(t)}{dt} = r\, V(t) \ - \ A(t).$$

Since depreciation is the negative of the rate of change in asset value,

$$(24) \qquad D(t) = A(t) \ - r\, V(t),$$

our final result.

This result differs from the discrete result only in the length of time interval. A comparison of the discount rates and final coefficient values for Equations 18 and 24 appears below.

Table 5: Comparison of i, r, and i/(1+i)

i	r=ln(1+i)	i/(1+i)
0.01	0.00995	0.00990
0.02	0.01980	0.01961
0.03	0.02956	0.02913
0.05	0.04879	0.04762
0.07	0.06766	0.06542
0.10	0.09531	0.09091

These values are all relatively close.

List of Figures:

Figure 1: Value of Example Reservoir Over Time

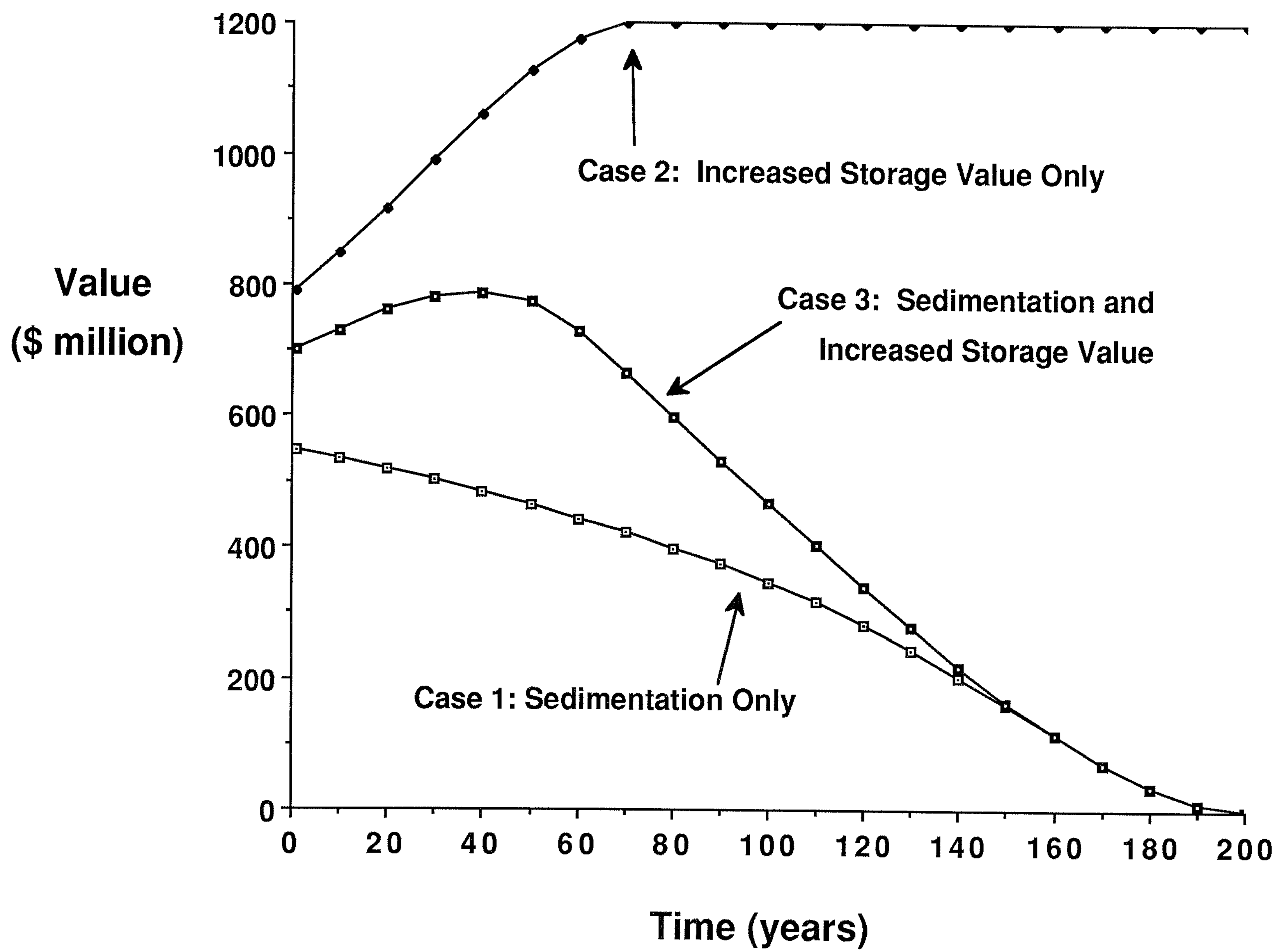


Figure 2: Appreciation/Depreciation for Example Reservoir

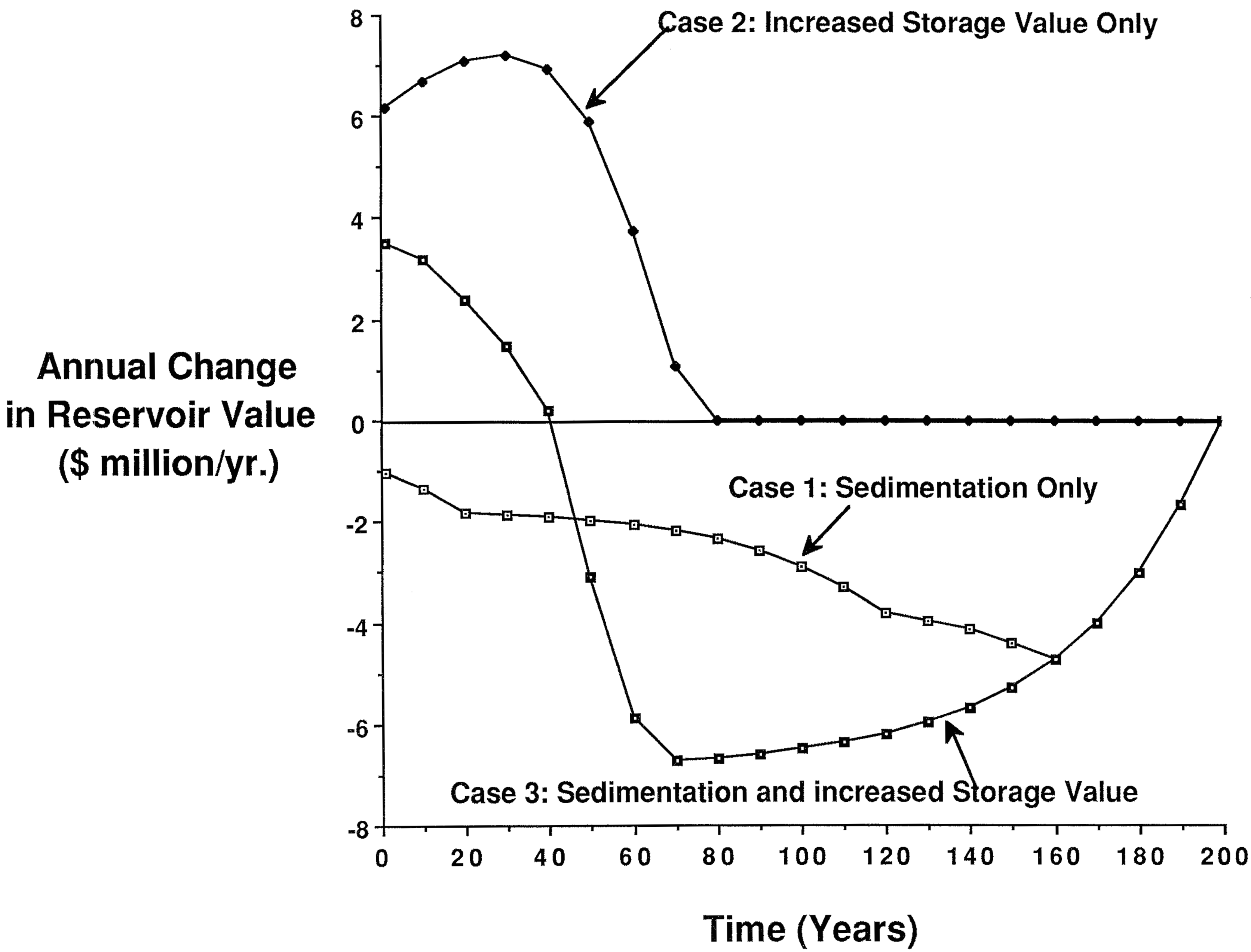


Figure 3: Case 3 Reservoir Values for Three Different Discount Rates

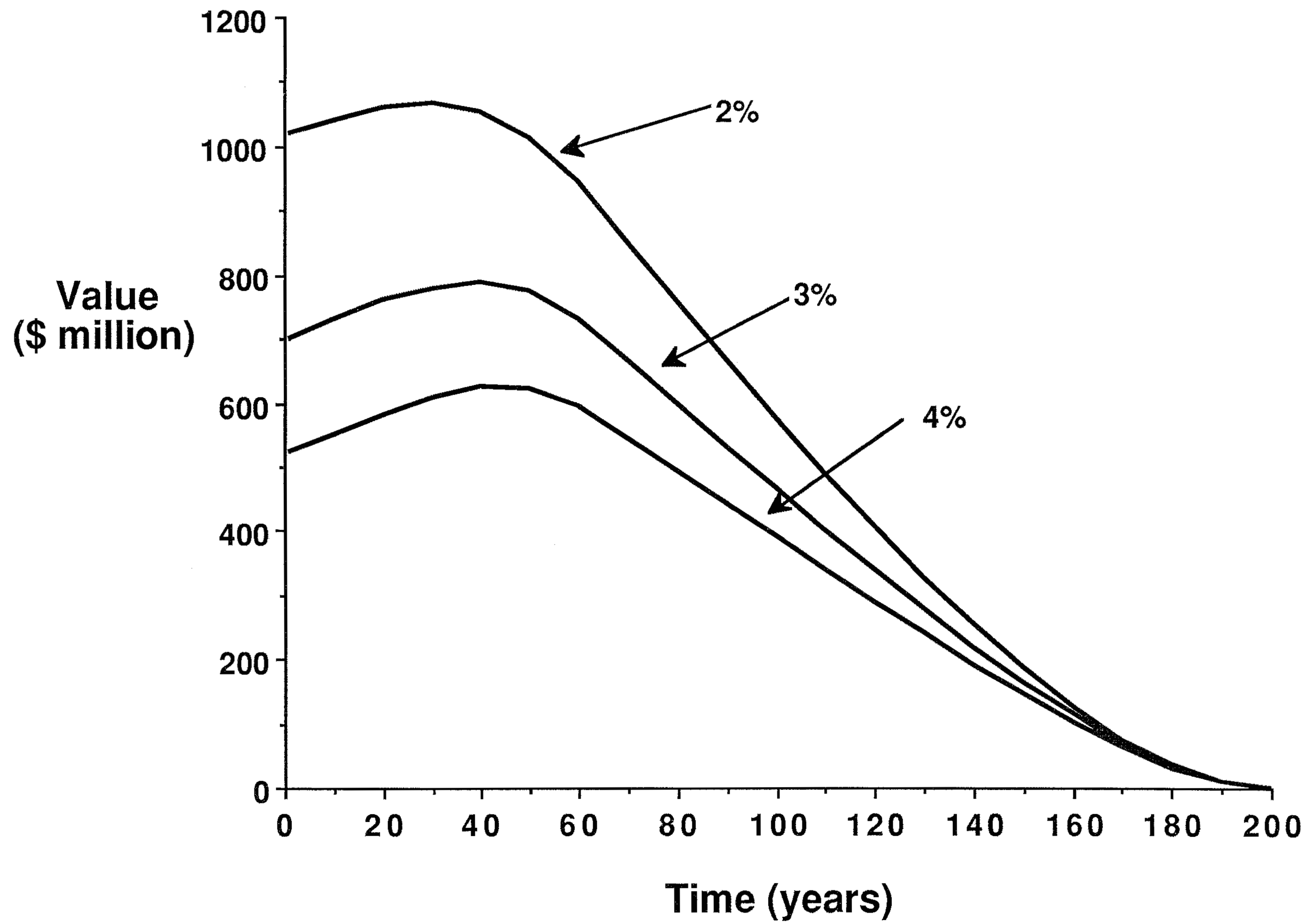
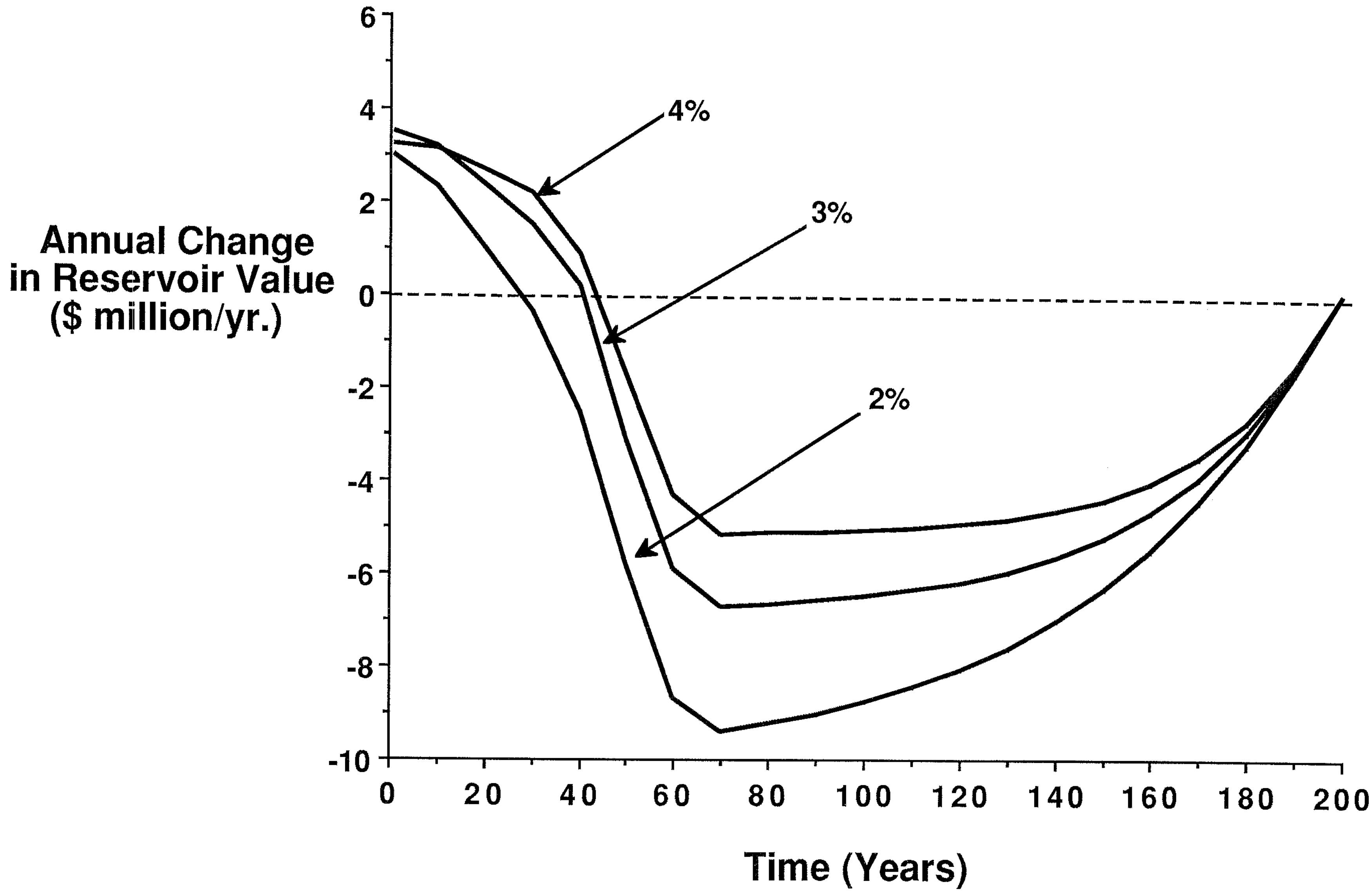


Figure 4: Appreciation/Depreciation For Case 3 For Three Different Discount Rates



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