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Water Practice & Technology Vol 14 No 4
doi: 10.2166/wpt.2019.063

A framework for cost-benefit assessment of alternative sediment management strategies in Dez hydropower reservoir: A probabilistic approach

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Abstract

A new theoretical approach to assessing the economic feasibility of sediment management strategies is proposed by incorporating probability distribution directly into the analysis. This would allow the life of Dez hydropower, for instance, to be prolonged definitely. The discount rate is also examined as a fundamental means of reflecting risk in discounted cash flow evaluations. Eight options for sediment management in Dez reservoir are assessed and future reservoir storage volumes estimated for the period 2018 to 2068. As a second step, discounted cash flow (DCF) with gamma discounting rate is used to evaluate present values for future cash flows for each option. The results indicate that these models, which offer an efficient approach, can be used to assess the cost-benefit feasibility of sediment management strategies. Guidelines are given for applying this approach to other projects.

Key words: cost-benefit assessment, discounted cash flow (DCF), gamma discounting rate, hydropower reservoir, sediment management strategies

INTRODUCTION

Sediment deposition in reservoirs causes loss of capacity, increased flood risk, degradation of water quality, and increased difficulty in reservoir operation and maintenance with consequent increases in associated costs (Auel *et al.* 2018). Sediment storage can have significant implications for the downstream ecosystems of large rivers. Substantial sedimentation problems experienced in many reservoirs, nationally and internationally, confirm that sediment management in reservoirs is a widespread problem (White 2001).

The substantial environmental and economic costs of restoring storage capacity by building a new dam are prompting a paradigm shift towards managing existing projects as renewable resources. Potential options can be divided into four general concepts (Nikolaos *et al.* 2017):

1. Watershed rehabilitation.
2. Sediment routing and bypass.
3. Sediment removal and flushing.
4. Compensation for in-reservoir sediment accumulation.

Combined consideration should be given to technical feasibility, environmental concerns and economic factors, to extend the useful lives of reservoirs. The cost and applicability of each strategy will vary from site to site. Studies of individual sites are needed to appreciate the complexity of sediment problems and the ways in which they can be controlled.

Soil erosion occurs in watersheds because of runoff from snow melt and rainfall. The eroded particles are transported through river systems and deposited in lakes, reservoirs, or oceans. When human activity accelerates sediment erosion rates, the process can lead to losses in ecosystem services (Molina-Navarro *et al.* 2014). Where properly undertaken, watershed management has been effective in reducing soil erosion, and is, therefore, seen as an effective way of reducing reservoir sedimentation rates. Unfortunately, in most cases, research and literature on the subject do not support this belief (Mahmood 1987). Annandale *et al.* (2003) report that intensive conservation efforts spanning several decades may be needed to reduce sediment yields by 10–20% for catchments exceeding 1,000 km^2. Such effort is also considered ineffective because of the large time lag between erosion control measure implementation and realization of reductions in sediment discharge in rivers. This arises because the sediment delivery ratio of large catchments is low, as large volumes of eroded material are stored at various locations in the watershed. Eroded material does not enter streams and rivers immediately, but is washed into them over successive storm events.

Sediment routing is most applicable to hydrologically small reservoirs where the water discharged by large sediment-transporting floods exceeds reservoir capacity, making water available for sediment release without curtailing beneficial uses. The bypassing of flood flow and sediment, to prevent them from entering a reservoir, requires certain topographic and flow conditions, and is unsuitable for sediment removal.

Flushing is one of the most economic methods, with the potential to recover lost storage without incurring dredging costs. Hydraulic flushing can be effective in removing sediments, emptying the reservoir through low-level outlets, and allowing natural flows to scour out deposits. On the other hand, flushing also releases large volumes of sediment downstream creating potentially serious problems (Khakzad & Elfimov 2015a) – e.g., in relation to downstream water quality and ecology (Sloff 1997). The high sediment concentrations released may have a significant impact on downstream biota (Morris & Fan 1998). When the reservoir is stratified, reducing conditions prevail at the bottom and resuspension of such deposits may lead, for instance, to the release of toxic elements, consumption of dissolved oxygen and freeing of NH_3 (Petitjean *et al.* 1997).

The literature on sediment management in reservoirs focuses mainly on engineering (Morris & Fan 1998). There is little, if any, published information on the economics of reservoir sedimentation and its implication for sustainable development.

To assess the economic feasibility of sediment management strategies, two related questions should be able to be answered: (1) is the cost incurred in sediment management activities worthwhile in terms of extending the dam's productive life, and (2) is it economic to extend a dam's life indefinitely?

In this study, carried out in relation to Dez reservoir, the economic evaluation methodology applied to the options considered is based on discounted cash flow (DCF), to compute the present values of the future cash flows that an investment would generate between 2018 and 2068.

MATERIALS AND METHODS

Sediment management options in Dez reservoir

Dez reservoir is in southern Iran. The dam is a large hydroelectric power source and was completed in 1963 by an Italian consortium (Figure 1).

When constructed, Dez dam was Iran's largest development project. It is a 203 m high, double-curvature arch dam, and its crest is 352 m above sea level. The original reservoir volume was $3,315 \times 10^6 m^3$, and the volume of sediment entering it has been estimated at $840 \times 10^6 m^3$ over a 50-year period. The reservoir's minimum and maximum operating water levels are 300 and 352 m above sea level, respectively. Although the dam is well-preserved, it is now more than 40 years old and reaching its midlife. The reservoirs' useful life is threatened by a sediment delta, which is approaching the dam's intake tunnels (Dezab Consulting Engineers 2004).

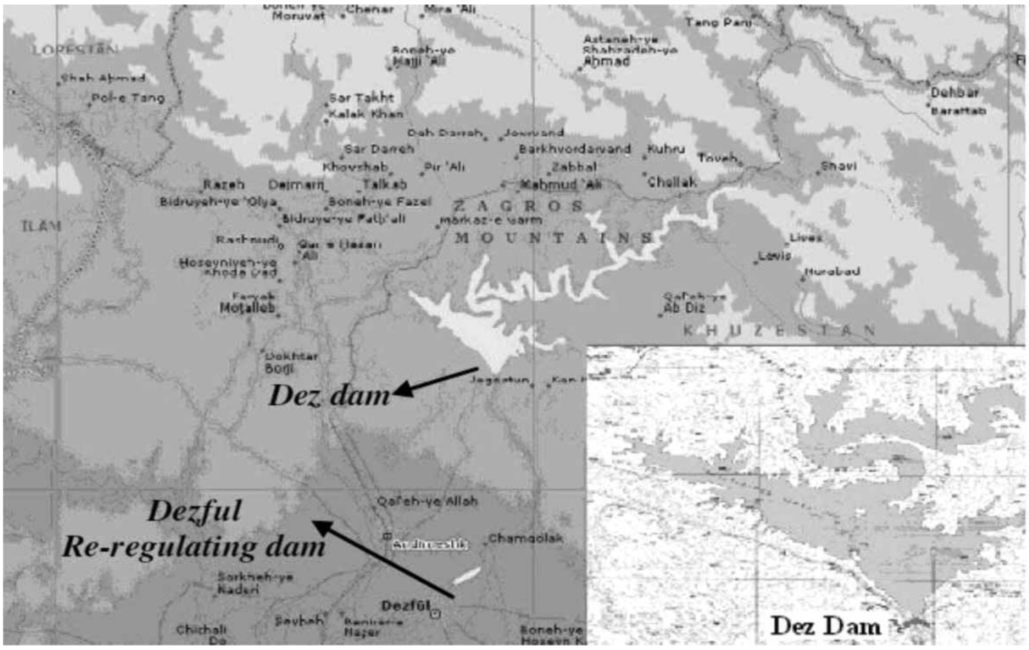

Figure 1 | Plan of Dez reservoir and dam.

Since about 2010, flushing has been used to remove the sediment that has accumulated immediately upstream of the irrigation outlets. No consideration has been given, however, to any negative environmental impacts downstream. Predictions indicate that between 1 and 1.5 Mm^3 of fine-grained sediment will be discharged annually downstream from the reservoir in future, by such flushing operations (Khakzad & Elfimov 2015b).

The major issue in Dez reservoir is the continual accumulation of silt near the dam. This has a potential impact on operations at the dam, including the irrigation outlets and power generation, as well as more generally. Several, broad strategies have been identified as potential means of managing the sediment accumulation and thus securing operation of the power project. The potential sediment management options can be divided into eight options:

(1) Watershed rehabilitation: this involves implementing remedial measures in the catchment to control sediment production and transport. Approximately 15% of the watershed's annual sediment yield can be controlled by management measures. However, this would not lead to any immediate reduction of sediment inflow, because check dam construction and forest planting would take several years.

(2) Irrigation outlet rehabilitation: it is considered essential to rehabilitate the existing Howell Bunger valves to (1) limit leakage from them, and (2) provide a means of drawing down the reservoir in an emergency. It is noted that the volume of storage retained was determined using the present volume of sediment flushed out annually (50% of the current input of 1.8 Mm^3/a) (Khakzad & Elfimov 2014).

(3) Irrigation outlet replacement: instead of rehabilitating the existing Howell Bunger valves, their complete replacement with slide gates has been considered. This would eliminate the present leakage issues, and provide a means of drawing down the reservoir and flushing sediment to maintain the wedge storage. A present value cost was calculated for this option, and assuming a sediment flushing effectiveness of 100% of the incoming turbidity current sediment.

(4) Access tunnel flushing: opening the existing upstream cofferdam access tunnel, to pass a reasonable discharge and flush out sediment accumulated in the power intake area.

(5) Reservoir dredging near the dam: dredging the sediment wedge deposited immediately upstream of the dam, which poses a threat to the power stations if it builds up above the power intake levels. This option is incremental to the cost of rehabilitating the irrigation outlets.

(6) Excavation of the upper delta: sediment excavation could be carried out in the dry, when the reservoir is drawn down to meet irrigation and other requirements. Excavation could reduce the rate at which reservoir storage is lost.
(7) Dam raising: the final option considered was raising the dam crest to provide additional storage. Raising was limited to 10 m for this evaluation, and the storage created is estimated at approximately 560 Mm^3 based on extrapolation of the existing volume-elevation curve.
(8) Do Nothing: a 'Do Nothing' alternative would eventually result in the turbidity current sediments entering the power tunnels and hence the units.

Simulation of future sedimentation in Dez reservoir for the period 2018 to 2068

A limited amount of information was provided on the historic rate of sedimentation in Dez Reservoir. Table 1 summarizes key information supplied on the hydrology and reservoir characteristics.

Table 1 | Summary of hydrology and reservoir characteristics

Description	Unit	Value
Minimum and maximum annual discharge (Dez River)	m^3/s	225–295
Average annual runoff (Dez River)	Mm^3	8,200
Mean annual sediment load	Mt/a	17.4
Start of reservoir filling		1962 (NOV)
Normal reservoir operating elevation range	masl	310–352
Initial reservoir storage volume	Mm^3	3,315.60
Average sedimentation rate	Mm^3/a	15.8

The estimates of mean annual discharge and runoff were based on monthly discharges for the 38-year period from 1963 to 2000. Table 2 shows the change in storage due to sedimentation for the same period. Comparison of the 1962 and 2002 surveys showed 617.0 Mm^3 of sedimentation (15.8 Mm^3/a). To provide further insight on sedimentation, maps of the reservoir's topography were digitized (Figure 2).

Table 2 | Sedimentation Observed – 1962–2002

	1962–2002		1972–2002		1997–2002	
Elevation (masl)	Sediment Volume (Mm^3)	Proportion of Total	Sediment Volume (Mm^3)	Proportion of Total	Sediment Volume (Mm^3)	Proportion of Total
< 230	87.4	14.1	51.4	12.1	0.0	0.0
230–250	128.0	20.7	128.3	30.2	19.4	−230.9
250–270	94.7	15.4	86.4	20.3	24.9	−296.4
270–290	82.5	13.4	45.9	10.8	4.2	−50.0
290–310	94.7	15.4	66.3	15.6	−4.5	53.6
310–330	113.5	18.4	57.2	13.4	−9.0	107.1
330–350	16.2	2.6	−10.1	−2.4	−43.4	516.7
Total	617.0		425.4		−8.4	

Approximately 260 Mm^3 of sediment (about 38% of the total) lie in the first 10 km upstream of the dam, and 470 Mm^3 (73%) within 30 km (includes the first 10 km) upstream (Table 2).

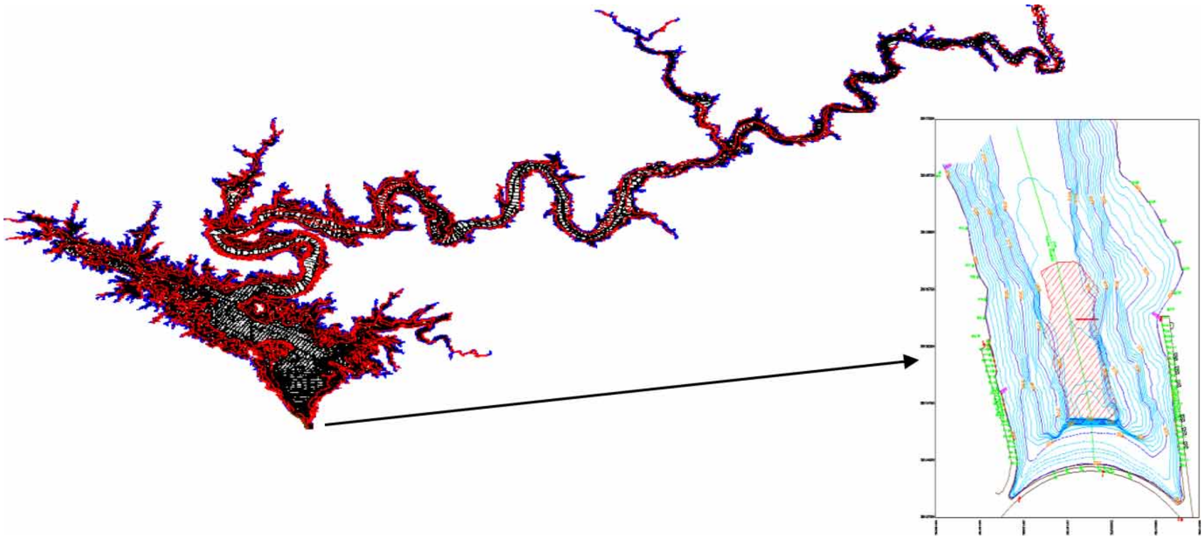

Figure 2 | Reservoir topography.

Daily flows, sediment volumes and reservoir levels for 2002 were available for analysis, and simple power-law regression was used to develop the rating curve, with some screening to eliminate outliers. The sediment load was determined using Equation (1):

$$G = 0.0387\,Q^{2.317},\ \ R^2 = 0.63 \tag{1}$$

where G is the sediment load (t/d), and Q the discharge (m^3/s). The size distribution and density of the material deposited in the reservoir are determined from gravity cores. These can be up to 8 m long, and are taken at 5 km intervals along the Dez River.

Preliminary economic evaluations

It is widely recognized that the economics of distant-future events, like sediment management in a reservoir – e.g., to extend its life – depend critically on the choice of discount rate, as the present value (PV) of a future benefit (or cost) is lower at higher discount rates (Kawashima *et al.* 2003). Due to the way that PV is calculated, this effect is greater the further into the future the benefit is discounted, and so the discount rate has a substantial impact on the economic viability of investment and measures for sedimentation management.

The discount rate for assessing the cost-benefit of different sediment management strategies has the same function as it does in the evaluation of any project. The risk adjusted discount rate is often built up starting with the corporate weighted average cost of capital (WACC) and adding increments of risk (Figure 3). This can also be expressed in terms of the real risk-free interest rate (the basic time value of money), plus the market risk premium, plus the project and country risks (Smith 2000, 2016).

The WACC equals the weighted average of the financial market costs. Specifically, it may be evaluated through the sum of two components: the cost of equity and the cost of debt. The weights represent the percentage of equity and debt respectively in relation to the total value of the company (Figure 4). WACC can be expressed in nominal and real terms, post- and pre-tax. No other methods for estimating the cost of equity were considered in this study.

In assessing a discount rate for a project, the country risk that comes with it should also be taken into account, and the equity risk premium is the logical input to show this. Some of the variation can be attributed to the country's position in the economic growth life cycle – those in early growth are more exposed to risk than mature countries (Damodaran 2008).

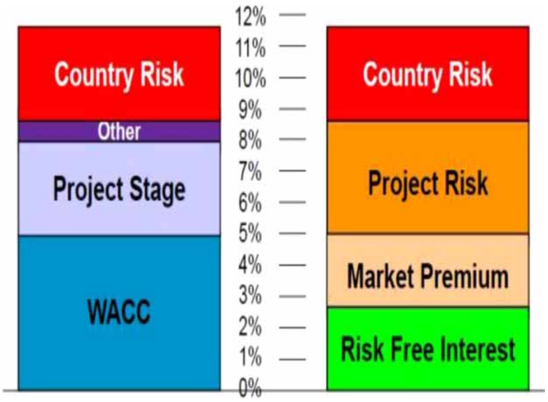

Figure 3 | Discount rate bases.

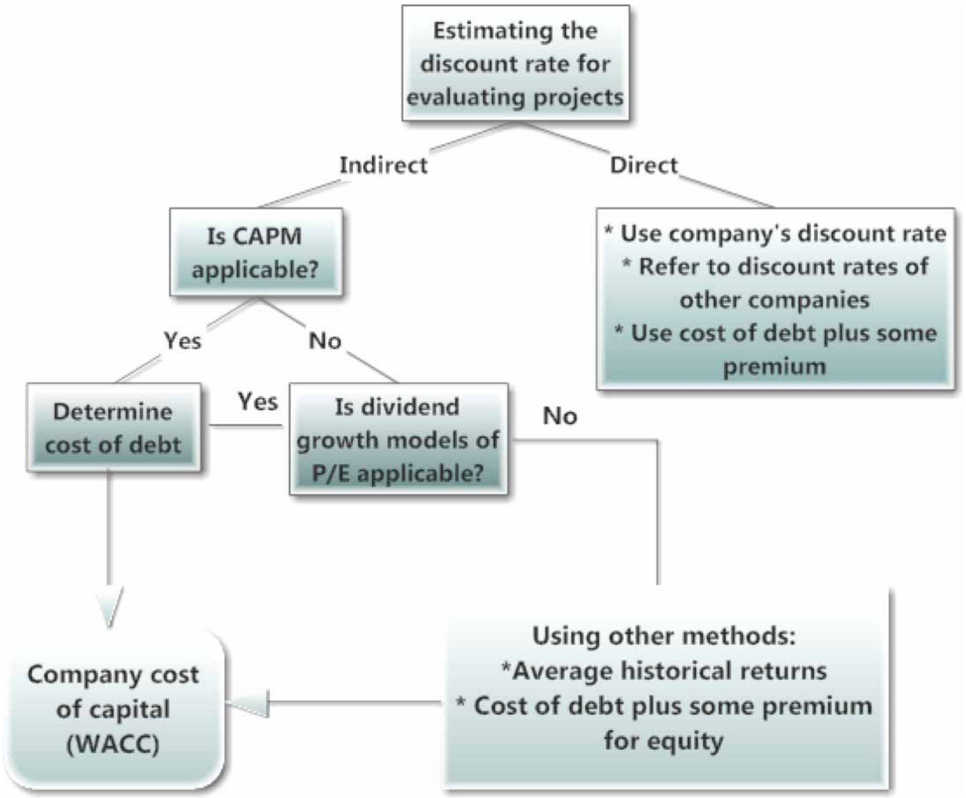

Figure 4 | Evaluation algorithm for WACC.

The different stages of a project present different levels of risk. Table 3 shows the premiums associated with different types of project depending on development stage or aim. In this case, the project has been designated 'early exploration' – i.e., a new construction project (Smith 2016, 2002; Southern Research 2017).

Table 3 | Risk premium project matrix

	Pre-Operating	Feasibility Study	Pre-feasibility Study	Early Exploration
Aimed at improving an existing project	−(3–5)%	0	3%	7%
Used to expand production	0	3–5%	6–8%	10–12%
Adding a new project to an existing complex	8–10%	11–15%	14–18%	18–22%

Weitzman (2001, 2010) suggested the analytically-tractable approach called gamma discounting, which gives a declining discount rate schedule as a simple, closed-form, function of time. The downward-sloping time profile of the discount-rate schedule – Table 4 – is sufficiently steep to make the equivalent 'as-if constant' discount rate much lower than the average discount rate of 4%.

Table 4 | Approximation recommended for sliding-scale discount rates

Time period	Name	Discount rate (%)
Within years 1–5	Immediate Future	4
Within years 6–25	Near Future	3
Within years 26–75	Medium Future	2
Within years 76–300	Distant Future	1
More than 300 years	Far-Distant Future	0

After discount rate evaluation, separate cash flows were prepared for the costs and benefits of each remedial option considered. Costs were broken down into capital, and operating and maintenance (O&M) costs.

The assessed benefits were grouped into two categories for analysis. The 'fixed benefits' category includes a predetermined demand and associated reliability requirement for water. The highest priority is given to domestic water supply, where reliability exceeding 95% would be expected. Reliability of approximately 80% has been set for water requirements associated with the irrigation sector.

The 'variable benefits' category benefits are relatively scalable with flow (firm or average) and consist primarily of power benefits.

The variable benefits are a function of the power output from the Dez project, and were assessed by determining the firm energy and capacity, and secondary energy. These benefits have been evaluated in terms of the cheapest thermal options. Two thermal processes were considered in this evaluation. Gas turbines were selected as the 'peaking' thermal option, while an oil-fired steam plant was selected as the 'base load' thermal variant. The power generation value was broken into peak and base thermal components as follows:

$$\text{Capacity Thermal}_{\text{Base}} + \text{Capacity Thermal}_{\text{Peak}} = \text{Capacity}_{\text{Firm Dez}}$$
$$\text{Energy Thermal}_{\text{Base}} + \text{Energy Thermal}_{\text{Peak}} = \text{Energy}_{\text{Firm Dez}}$$
$$\text{Energy Thermal}_{\text{Base}} = \text{Capacity Thermal}_{\text{Base}} * \text{Plant Factor}_{\text{Base}} * \text{Hours per year}$$
$$\text{Energy Thermal}_{\text{Peak}} = \text{Capacity Thermal}_{\text{Peak}} * \text{Plant Factor}_{\text{Peak}} * \text{Hours per year}$$
$$\text{Plant Factor Base} = 75\%$$
$$\text{Plant Factor Peak} = 10\%$$
$$\text{Energy}_{\text{Secondary}} = \text{Energy}_{\text{Total Dez}} - \text{Energy}_{\text{Firm Dez}}$$

Once the thermal capacity and energy values had been determined, the present worth of various equivalent thermal costs was computed:

- capital costs with interim replacement
- fixed operating and maintenance costs
- variable operating and maintenance costs, including fuel.

Secondary energy from the system was also evaluated in relation to the lowest fuel and variable O&M costs, which corresponded to the base load option.

The values assigned to these costs were taken from standard costs provided by Tavaneer (Ministry of Energy of Iran) (Dezab Consulting Engineers 2004) for economic assessments at feasibility-level. They are summarized in Table 5.

Table 5 | Thermal option data

Parameter	Units	Base	Peak
Plant type		Oil-fired Steam	Gas Turbine
Installation cost	USD/KW	564.79	303.78
Mean annual non-availability		26%	20%
Plant life	Years	30	15
Plant factor		75%	10%
Interim replacement	% of Capital Cost	0.35%	0.35%
Fixed O&M	USD/KW-Yr	3.36	1.12
Variable O&M	USD/KWh	0.0002	0.00011
Fuel costs at year 0	USD/KWh	0.019	0.112
Fuel cost escalation	Per annum	0.00%	0.00%
Secondary energy value	Dollars/KWh	0.0191	Not applicable

The sediment management options considered will result in varying degrees of sediment exclusion from the generating units. For example, a 'do nothing' option would eventually result in turbidity current sediments entering the power tunnels and hence the units. Other options could reduce or avoid this problem. Thus it is important in the comparison to assess the extent to which the generation benefits are affected by changes in generating equipment efficiency caused by the passage of sediment over the facilities' life. To reflect this impact, each option was evaluated in terms of the degree that it would inhibit sediment entry to the power intake. Table 6 shows the generating efficiency reductions applicable to the varying degrees of sediment exclusion (EPRI 2000).

Table 6 | Thermal generation efficiency losses vs sediment exclusion rates

Sediment Exclusion Rate	Option	Efficiency Loss
Good	– replace Howell Bunger valves with slide gates – dredge near dam	0.06% per year (normal wear and tear)
Limited	– rehabilitate Howell Bunger valves – excavate in delta – Manage watershed	0.12% per year
None or Poor	– do nothing – raise dam crest (with existing power tunnel arrangement)	0.18% per year

When considering mutually exclusive options, the net present value (NPV) of costs and benefits, or net present worth, method must be used. For independent options, however, the benefit-cost (B/C) ratio could be used. In this study, some options are mutually exclusive (e.g., flushing and dredging near the dam), while others are independent (watershed management, dam raising and delta excavation).

RESULTS AND DISCUSSION

A brief comparative modeling assessment of sedimentation was undertaken based on an extrapolation of the existing volume-elevation curve, using Mike 11, including its sediment module, and, separately, with the HEC-6 model (US Army Corps of Engineers 1993; Danish Hydraulic Institute 2014). The results are presented in Figure 5 for each option for the years 2018 and 2056. The data used included:

- daily flows from the wet period in 2017 (6 months).
- approximate sediment gradation data from the 1972 Reservoir Sedimentation report (Khuzestan Water & Electricity Organisation (KWEO) 2003).
- the suspended sediment rating curve from 2002.
- cross-sections from the 1957 topographic map (Khuzestan Water & Electricity Organisation (KWEO) 2003).
- the estimated total sedimentation volume (1963 to 2018) = 617.1 Mm^3.
- the average annual long-term sedimentation rate: 15.8 Mm^3/a; and,
- the annual turbidity load = 1.8 Mm^3.

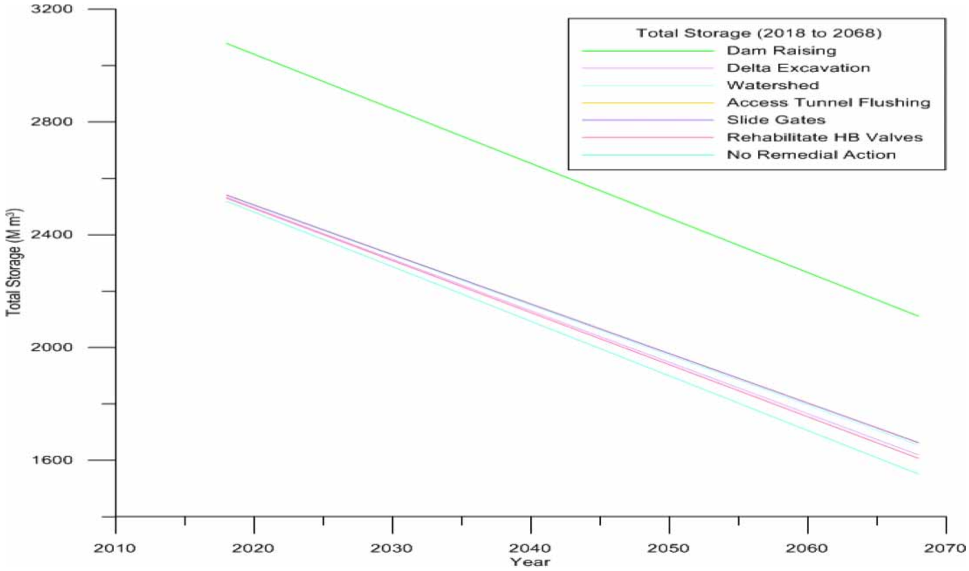

Figure 5 | Total storage in relation to the various options.

The analysis of each management option's impacts was carried out using simulation of use of the available flow for storage, power generation, water supply for irrigation and other uses. The primary output from the simulations was used to determine power and energy benefits, as well as water supply reliability.

In order to calculate cash flows, the discount rates were also evaluated, regardless of WACC and adding risk increments. WACC can be expressed in either nominal or real terms, post- and pre-tax (Australasian Institute of Mining & Metallurgy 2005). A nominal WACC includes the impact of inflation. In Iran the nominal WACC for construction companies is calculated as shown in Table 7.

Table 7 | WACC for construction companies in Iran (Central Bank of Iran 2017)

WACC	11.20%
Weight of debt	16%
Corporate tax rate	22.50%
Cost of debt	7.80%
Annual inflation rate	9.20%
Risk free rate	5.50%
Unlevered beta (The volatility of returns for a business, without considering its financial leverage)	0.99
Market premium	5.70%

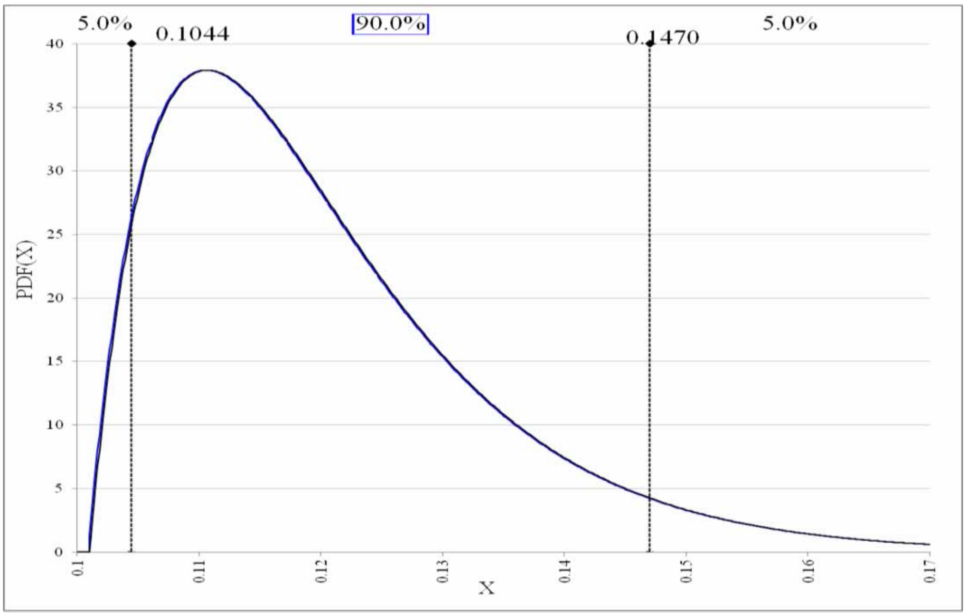

Figure 6 | Gamma PDF for discount rate in Dez hydropower sediment management.

The risk adjusted discount rate for sediment management was calculated using:

+ WACC expected return for company (nominal): 11.2%
+ adjust for project's development stage: 0% (Table 4)
+ adjust for technology risk: 0.0%. (Technical premium: low risk 0.0%, moderate risk 0.5%, high risk 1.0%)
+ adjust for remoteness: 0%. (Not remote 0.0%, somewhat remote 0.5%, very remote 1.0%)
+ adjust for country risk: 2.1%
  = risk adjusted discount rate for project (nominal) 13.3%

Using economic surveys in Iran (Amiri 2015) and Table 4, the gamma distribution discount rate for sediment management strategies in Dez Reservoir is considerable. The gamma distribution is a family of right-skewed, continuous probability distributions. The gamma distribution can be parameterized in terms of a shape parameter, α, and an inverse scale parameter, β. A shift parameter can be added, so that the x domain starts at a value other than zero. With $\alpha = 2$, $\beta = 0.01$, and shift = 0.1, the mean and

Table 8 | Data used in sample calculation of the cost of watershed rehabilitation

Total catchment area	17,365	km^2
Effectiveness factor	15%	
Treated catchment area	2,605	km^2
Treatment cost	0.017	MUSD/km^2
Proportion of catchment treated annually	6.67%	
Annual treatment cost	2.98	MUSD
Discount rate	= Gamma ($\alpha = 2$, $\beta = 0.01$, shift = 0.1)	p.a.
Total treatment time	15	Years
Annual O&M	5%	Treatment cost to date
Maximum sediment reduction arising from full treatment	15%	
Current sediment inflow	19	Mm^3/a

standard deviation for the discount rate gamma distribution are 12 and 1.3% respectively. With the values α, β and shift, the implied gamma probability density function (PDF) is shown as the curve in Figure 6.

After evaluation of the discount rate, the NPVs of the various options were determined from the relevant CAPEX and OPEX, as outlined. If sediment is flushed through the outlet, or dredged and discharged over the spillway, into the river, it might be deposited in the Dez re-regulating reservoir (Figure 1). Because of that, the cost of dredging in the re-regulating reservoir has been included in

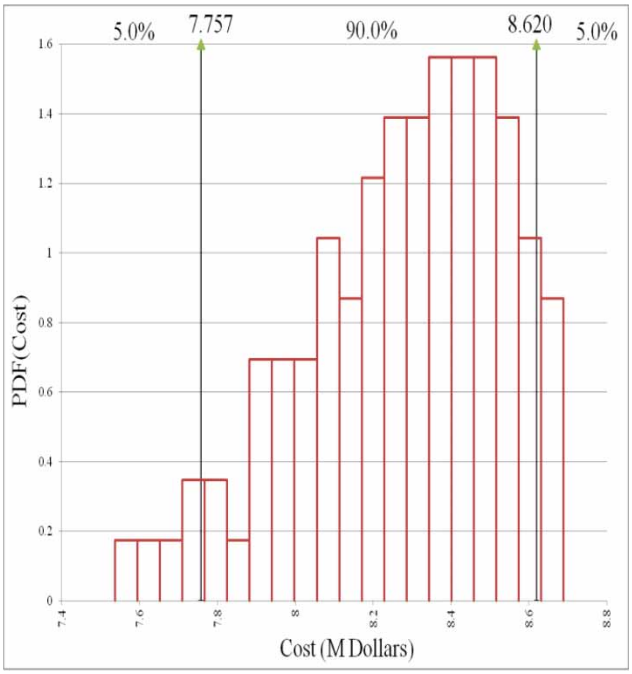

Figure 7 | PDF of cost of irrigation outlet rehabilitation.

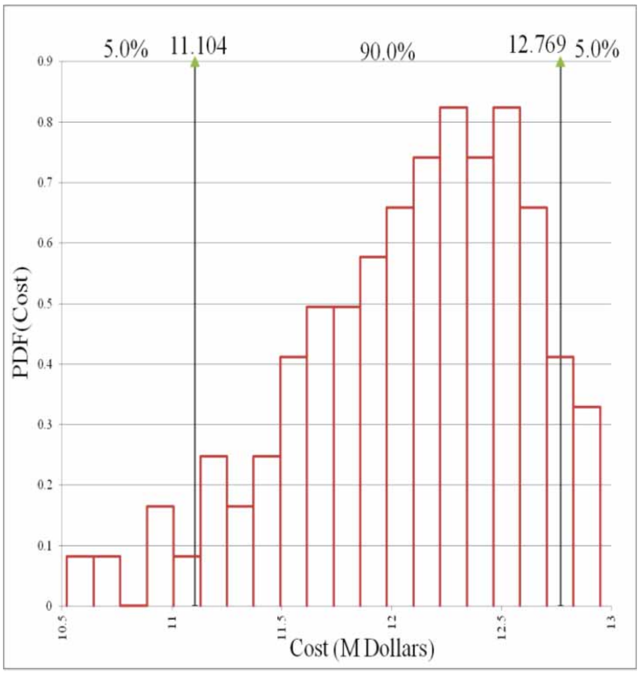

Figure 8 | PDF of cost of irrigation outlet replacement.

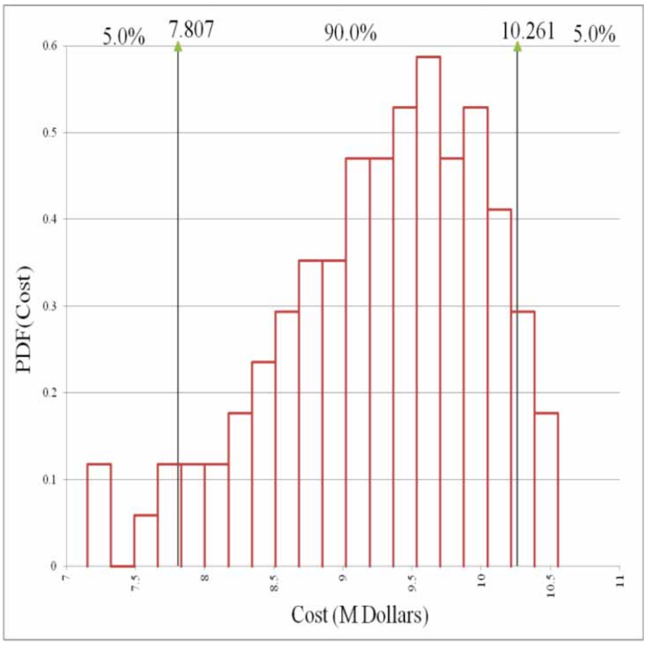

Figure 9 | PDF of cost of dredging near the dam.

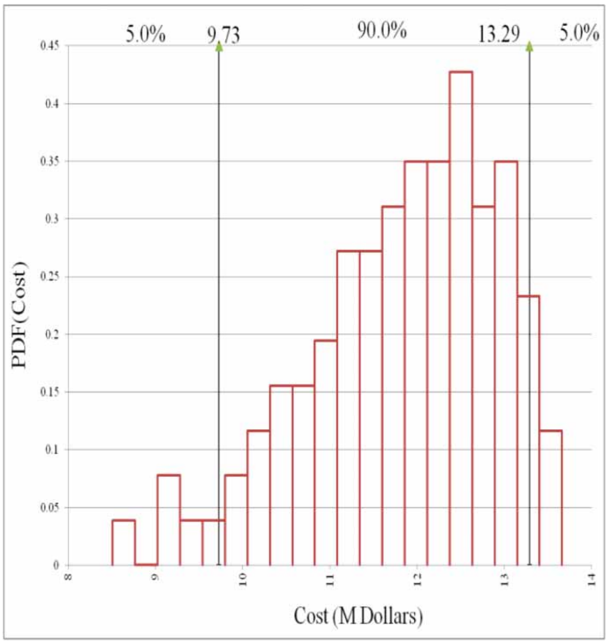

Figure 10 | PDF of cost of excavation of upper delta.

the costs of these options to determine their total costs. The data used in the sample calculation of the cost of watershed rehabilitation and the costs of the various sediment management options are shown in Table 8, and the costs (in millions of US dollars) in Figures 7–13. Table 9 shows the unit cost per storage increment for each option, based on Figure 5.

It is clear that raising the dam crest offers the lowest unit cost for additional storage. However, this would still require flushing to provide an emergency draw down capability. The watershed management option is likely to be very expensive even if effectiveness is as high as 30%. The best options, for further evaluation, appear to be replacement of the Howell Bunger valves with slide gates (alternative to the base case) and raising the dam crest (additional to the base case).

The power-generation benefits associated with the various options were also evaluated (Figures 14–21) using the standard costs from Tavaneer (Ministry of Energy of Iran) (Dezab Consulting Engineers 2004). Sample calculation data used in calculating the benefit of raising the dam crest are given in Table 10.

Comparison of the net benefits indicates that three options are ranked high – replacement of the Howell Bunger valves with slide gates, dredging near the dam, and raising the dam crest. Raising the dam crest produces the highest NPV benefits and addresses the loss of storage volume directly. It would have to be combined with rehabilitating or replacing the irrigation outlets, however, to address the potential for power intake sedimentation and maintain the reservoir's drawdown capabilities. It also involves much more significant technical and environmental issues than

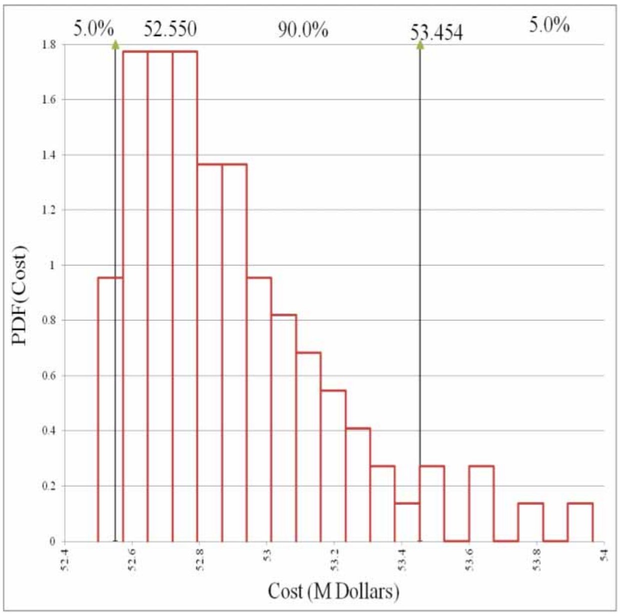

Figure 11 | PDF of cost of raising dam crest.

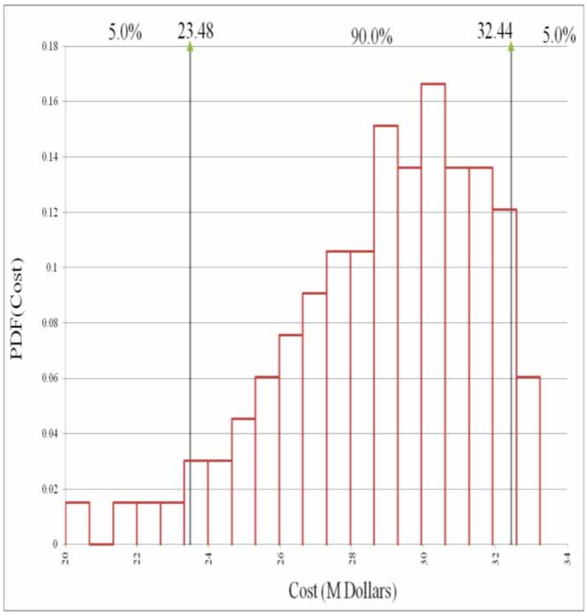

Figure 12 | PDF of cost of watershed rehabilitation.

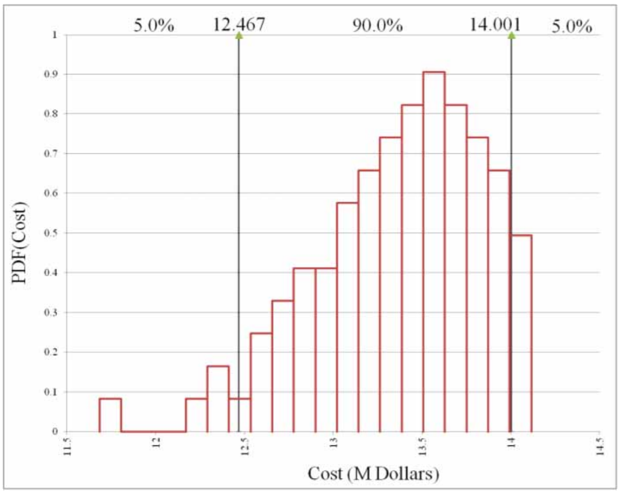

Figure 13 | PDF of cost of access tunnel flushing.

Table 9 | Unit cost of retained/created storage (USD/m^3)

Option	Best-case estimate	Most probable estimate	Worst-case estimate	5%	95%
Watershed rehabilitation	2.28	2.54	3.46	2.32	2.87
Irrigation outlet rehabilitation	0.99	1.11	1.45	1.01	1.26
Irrigation outlet replacement	0.74	0.81	1.00	0.75	0.90
Access tunnel flushing	0.81	0.89	1.25	0.82	1.01
Excavation of upper delta	1.27	1.29	1.33	1.27	1.31
Dredging near the dam	0.92	0.95	1.02	0.92	0.99
Dam crest raising	0.09	0.09	0.10	0.09	0.10

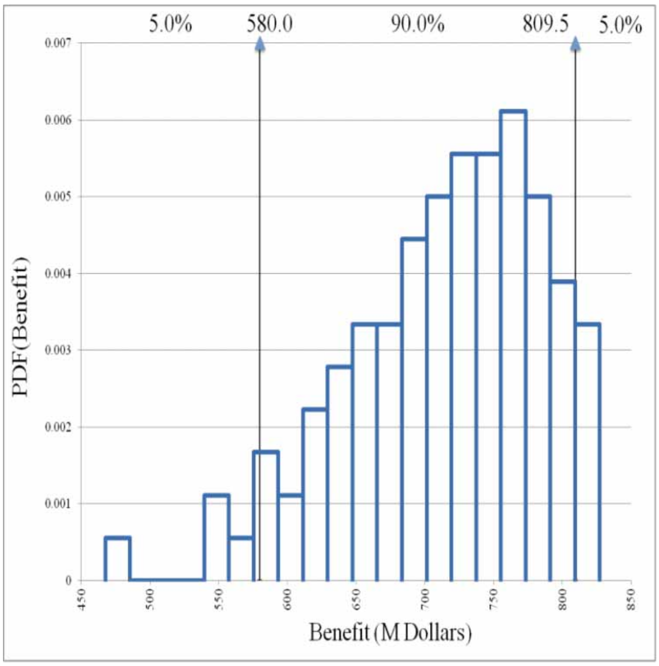

Figure 14 | PDF of benefit of watershed rehabilitation.

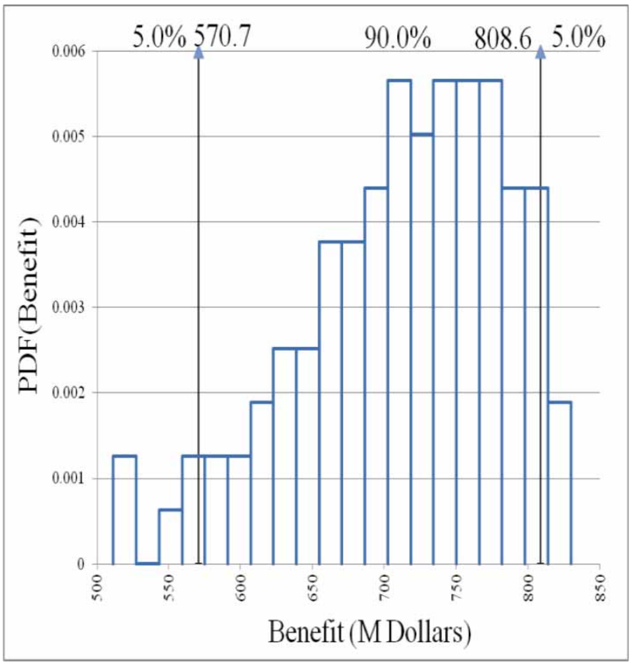

Figure 15 | PDF of benefit of irrigation outlet rehabilitation.

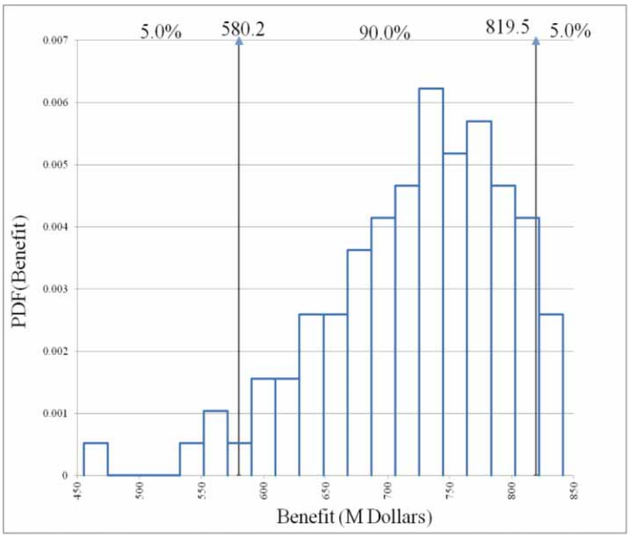

Figure 16 | PDF of benefit of irrigation outlet replacement.

the other options. Irrigation outlet replacement yields a positive net benefit because it was judged possible to flush out the sediment in the wedge without causing major damage. Dredging is very sensitive to operating costs and produces NPV benefits ranging from a small positive value to negative.

SUMMARY AND CONCLUSIONS

The cost-benefit and applicability of each sediment management strategy vary from one site to another. In this study, a significant number of sediment management options were identified for

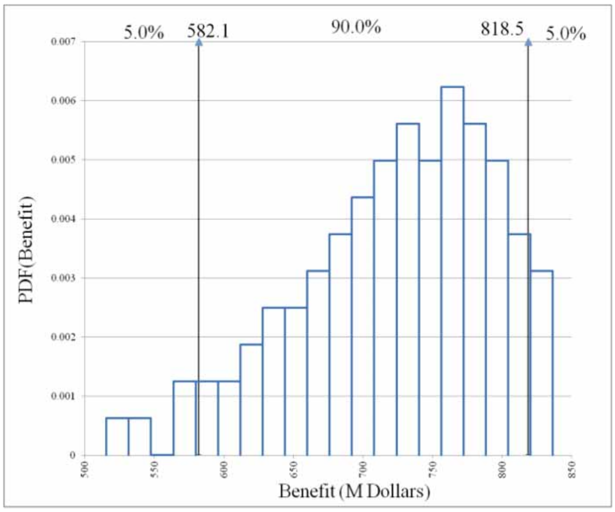

Figure 17 | PDF of benefit of access tunnel flushing.

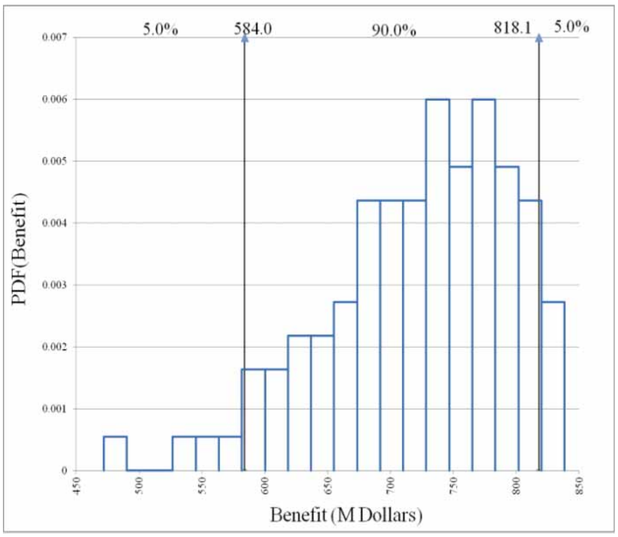

Figure 18 | PDF of benefit of excavation of upper delta.

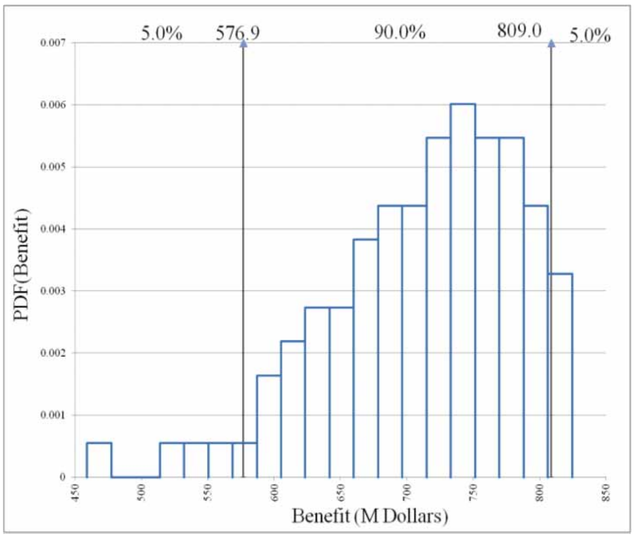

Figure 19 | PDF of benefit of dredging near the dam.

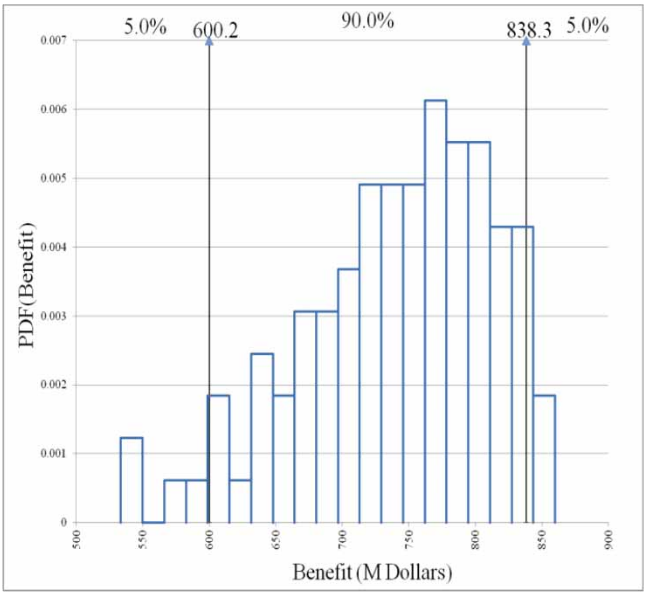

Figure 20 | PDF of benefit of raising the dam crest.

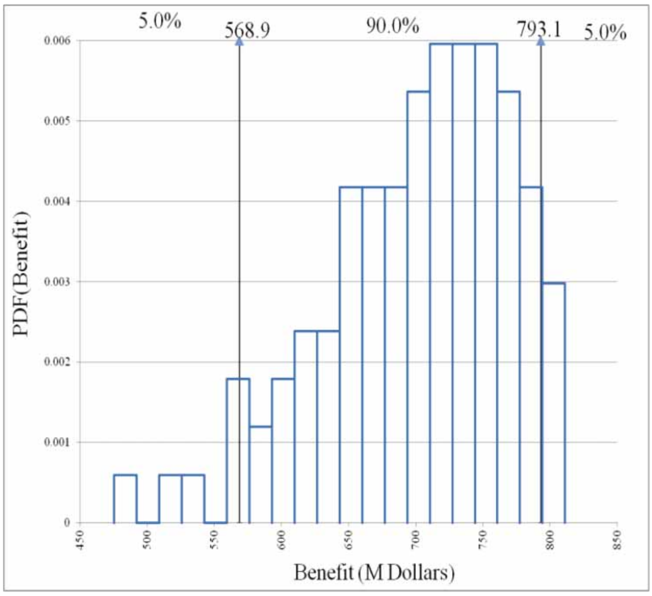

Figure 21 | PDF of benefit of taking no remedial action.

Dez hydropower reservoir. The reservoir storage volumes for the different options in the period 2018 to 2068 were assessed, and the DCF technique used to calculate the NPVs of future cash flows. The gamma distribution for the discount rates was also evaluated in relation to WACC, to the project development stage, and the sliding-scale discount and country risk rates. An economic analysis of the options yielded numerical values for unit storage costs (i.e. the cost per cubic meter of providing additional reservoir storage for each option), total benefits and net incremental benefits. On the basis of net benefits, replacing the Howell Bunger valves with slide gates, dredging near the dam, and raising the dam crest, were ranked highly.

The results of ranking the sediment management options in this way show that the method is a powerful tool for selecting the optimum response scenario against the identified risks, and could be used for preliminary economic evaluations elsewhere.

Table 10 | Data used to calculate the benefit of raising the dam crest

1) Station Data		
Installed capacity	583.5	MW
Firm capacity	320.7	MW
System firm energy capacity	76.5	GWh
System average energy capacity	2,595.3	GWh
2) Economic Data		
Discount rate	$=\text{Gamma}(\alpha=2, \beta=0.01, \text{shift}=0.1))$	p.a.
3) Peak Thermal Option Data		
Installation cost	303.78	USD/KW
Overall non-availability	20.0%	
Plant life	15	Years
Plant factor	10%	
Interim replacement	0.35%	
Fixed O&M	1.12	USD/KW-pa
Variable O&M	0.0001	USD/KWh
Fuel costs at year 0	2.89	USD/KWh
Fuel cost escalation	0.0%	
4) Base Thermal Option Data		
Installation cost	564.78	USD/KW
Overall non-availability	26.0%	
Plant life	30	Years
Plant factor	75.00%	
Interim replacement	0.35%	
Fixed O&M	3.36	USD/KW/a
Variable O&M	0.00017	USDls/KWh
Fuel costs at year 0	0.0189	USD/KWh
Fuel cost escalation	0.0%	
5) Displaced Generation		
Displaced peak capacity	356.64	MW
Displaced peak energy	312.63	GWh
Displaced base capacity	−35.92	MW
Displaced base energy	−236.13	GWh
Displaced secondary energy	2,518.80	GWh
Total displaced capacity	320.72	MW
Total displaced energy	76.5	GWh

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