Water Policy 22 (2020) 328–347

Cost–benefit analysis of restoring an ephemeral desert stream after an ecological accident

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Abstract

This paper presents a methodology for examining the net benefit of site rehabilitation after an ecological disaster. While restoration of the site seems reasonable on the face of it, the cost of proactive restoration can be very high. In this article, we present a tool for decision makers to decide on the optimal route to rehabilitation – proactive or natural rehabilitation (or some combination thereof). We present a case study of an ecological catastrophe that occurred in June 2017 at an ephemeral desert stream in the south of Israel. We estimated the restoration costs and the benefits of restoration over the relevant time frame using a contingent valuation method. Comparing the present costs and benefits revealed a net present value of ILS 355.5 million in favor of proactive restoration of the stream. We also demonstrate that not all sections of the stream pass the benefit cost test, so a higher net benefit could be achieved through partial restoration. Our study demonstrates the importance of cost–benefit analysis when policy makers are contemplating proactive versus natural restoration.

Keywords: Contingent valuation; Cost–benefit analysis; Damage compensation; Environmental accidents; Ephemeral stream restoration; Israel

Highlights

- Ecological damage creates an array of opportunities for restoration and recovery.
- Pro-active restoration should be justified on a cost–benefit basis relative to natural recovery.
- We perform the analysis on the Ashalim stream in Israel based on the ecological accident in 2017.
- Benefits were derived from a Contingent Valuation study.
- Results show that in most segments of the stream pro-active restoration has a positive net benefit.

doi: 10.2166/wp.2020.014

1. Introduction

Restoration is a major component of responses to ecological accidents and must be considered in damage estimates to determine the amount of compensation owed to landowners by the responsible parties (Barnthouse & Stahl, 2002). Compensation should be based on restoration costs plus the value of the remaining resources whose restoration is still pending (Bullock & O'Shea, 2016).

Most papers dealing with ecological disaster are concerned with benefits from restoration but do not justify them on grounds of a cost–benefit analysis (CBA) (e.g., Grigalunas *et al.*, 1999; Bishop *et al.*, 2017). Wainger & Mazzotta (2011) argued for greater efforts to conduct CBA to justify interventions in these cases, as did Wattage *et al.* (2000), who specifically argued for the use of contingent valuation (CV) to perform CBA of changes in river water quality. This is a major aim of this manuscript. That is, to better justify restoration efforts as such that the derived benefits outweigh their costs.

There are a few examples of detailed cost analysis in similar cases of river and other aquatic bodies pollution (e.g., Loureiro *et al.*, 2006), but a comparable analysis of benefits is usually missing (Becker *et al.*, 2019). On the other hand, many studies have recognized that it may be impossible to totally restore the injured area (e.g., Becker & Katz, 2006; Moreno-Mateos *et al.*, 2012), and that compensating the community by restoring a different but somehow equivalent ecosystem may be a better option (e.g., Strange *et al.*, 2002; Lavee, 2010; Levrel *et al.*, 2012). However, analyses of these scenarios only compare costs without quantifying the respective benefits of each proposal (Scemama & Levrel, 2016). This is another missing piece that this study provides. Specifically, the study presents an application of CBA to a case study of the Ashalim ephemeral stream in the southern part of Israel, which suffered a major ecological accident in 2017. The goal of this analysis is to shed light on two possible restoration options: Pro-active restoration vs. natural recovery. Each has its own dynamic of benefits and costs and as we show, in most segments of the stream the pro-active option has higher net benefit than the natural recovery option.

The next section describes the area and provides background on the ecological disaster. Section 3 describes the methodology used to estimate the cost of the restoration plan and the benefit from restoration, while Section 4 offers the actual calculations for this case and Section 5 describes the results of the analysis. Section 6 discusses the significance of the results, and Section 7 concludes and provides overall assessment and recommendations for further research.

2. Site description and background of the accident

The Ashalim ephemeral stream, on the border of the Judean Desert and the northeast part of the Negev Desert (part of the world desert strip), boasts beautiful rocky canyons and (during ephemeral flow) an impressive waterfall. It is a short and steep ephemeral stream that drains an area of about 80 square kilometers between the Rotem Plain in the west and the Dead Sea in the east, and a deep ravine that has water for several months each year. The Ashalim has for many years been the focus of trips for individuals and groups, with tens of thousands of visitors each year (Greenbaum, 2007).

The Ashalim stream also has regional importance as an ecological corridor connecting the Negev to the Judean Desert and is crucial for the future of Israeli ibex populations[1]. It crosses four main ecological units in the Negev: inner sands, reservoirs and desert shrubs, extreme desert, and desert salt flats. It can be divided into several natural ecological units (habitats), according to the differences in the geomorphology and flora along it: dune unit, dune rock unit, shallow and deep units, shifting channel, Northern Ashalim Reservoir and Southern Ashalim Reservoir (Figure 1). The Southern Ashalim Reservoir is the habitat of many waterfowl and serves as an important stopover for migratory birds.

In June 2017, the wall of an evaporation pond at the Rotem fertilizer plant gave way, and at least 100,000 cubic meters of acidic water, containing gypsum, heavy metals, nitrogen, sulfur and fluoride, flowed along the Ashalim from the Rotem Plain to the Ashhalim reservoirs. The resulting contamination of the area will persist for many years and affect its ecological function. Portions of the ephemeral stream were also damaged, severely diminishing its economic value (Justo *et al.*, 2019).

The main damage was to vegetation along the stream. The contaminated water killed plants; this damage was assumed to have an immediate and negative effect on the carrying capacity of all species in the area, since they all rely, directly or indirectly, on the primary production of the plants. Another important component that appears to have been damaged is soil crusts, which have a variety of ecological functions, including fixing carbon, binding nitrogen, and preventing soil erosion. Animals were also killed: birds, mammals, reptiles, insects and arthropods. Beyond the damage that is currently observable, the Nature and Parks Authority expect to see more damage in the future, including soil toxicity and accumulation of pollutants in the soil; pollution of surface water; damage to acacia trees; and soil pollution at depth[2]. These issues preclude human visitation; the reserve, which used to host about 20,000 visitors a year, has been closed until further notice.

3. Methods

3.1. Combined cost of damage reduction and restoration

Our analysis was based on tracing the combined cost of damage reduction and restoration (Figure 2). Restoration can take different paths. The orange line in Figure 2 represents the baseline (or existing) environmental value of the ephemeral stream's ecosystems. When the accident occurred, these values started to decrease (blue line). The downward slope indicates that the value was not lost immediately, but over some period. Later, a natural recovery process began, which might or might not lead to complete rehabilitation. In our case, the restoration would not be complete, so the blue line eventually flattens to a steady state at a lower value.

Active restoration (red line) is predicted to reduce the damage of an accident and speed the recovery process. Like natural restoration, it would be only partially successful, leading to a steady-state environmental value for the ephemeral stream that is not quite the same as the baseline. While it would end up

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[1] The Nubian ibex can be found in four areas in Israel, including this desert. The current population in this region is estimated by about 250 individuals, inhabiting steep cliffs separated by deep wadis. Protecting them requires provision of ecological corridors to enable them to reach sources of water and food (Shkedy & Saltz, 2000).

[2] See a detailed description of the accident and its consequences as reported by the Nature Protection Agency in: https://www.parks.org.il/new/ashalim/.

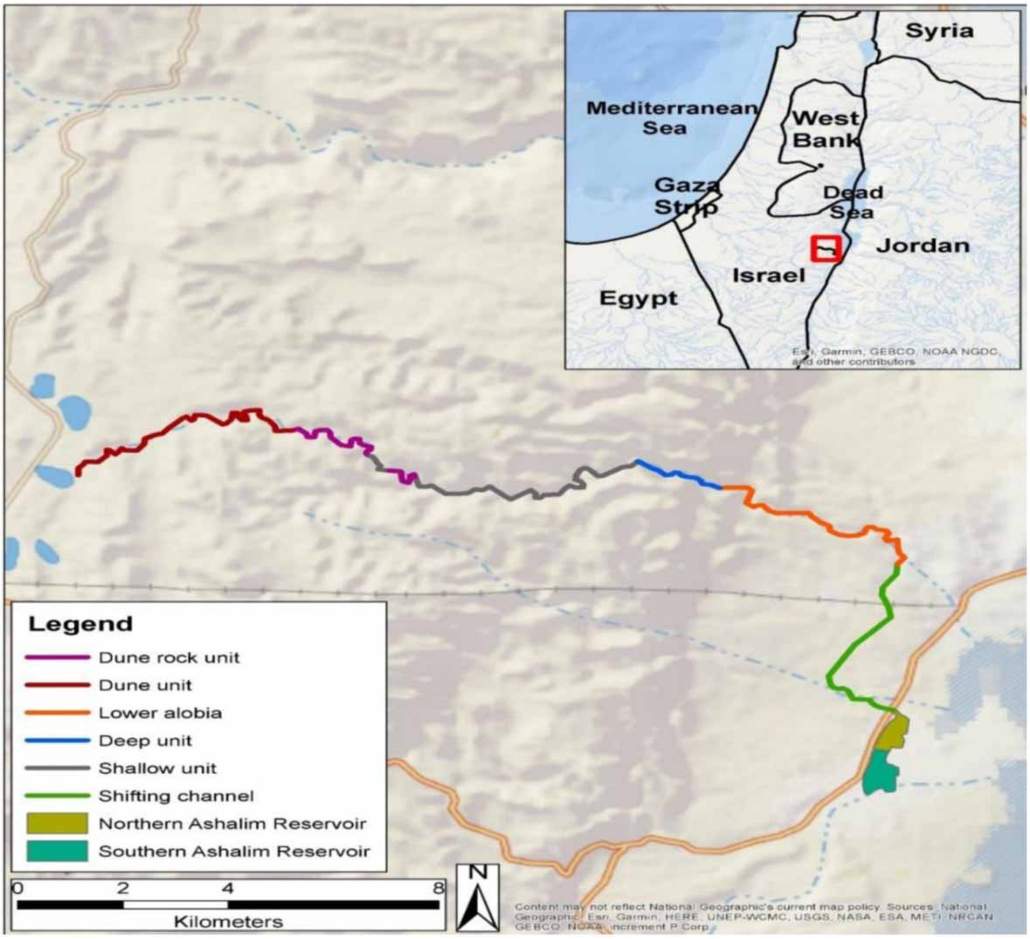

Fig. 1. Map of the Ashalim stream basin*. *Source*: Authors' own work, created using ArcGIS and Survey Israel. Please refer to the online version of this paper to see this figure in color: http://dx.doi.org/10.2166/wp.2020.014.

closer to the baseline environmental value than natural recovery (blue line), it is still below the baseline value (orange line).

With no active restoration effort, the value of the damage is represented by the area A + B. Active restoration reduces the value of the environmental damage by the cost represented in area B. Here, two points should be made clear. First, reducing the value of the damage from A + B to just A has a cost. Therefore, such efforts should be subjected to a CBA. If such an effort passes the cost–benefit test, the polluter is then liable for area A, in addition to the cost of active restoration (which is less than the area of B).

The natural recovery path yields the following discounted value of damages:

$$\text{Damage}_{\text{nr}} = \sum_{t=0}^{\infty} (D_t(1 - \text{NR}_t)/(1 + r + z)^t) \tag{1}$$

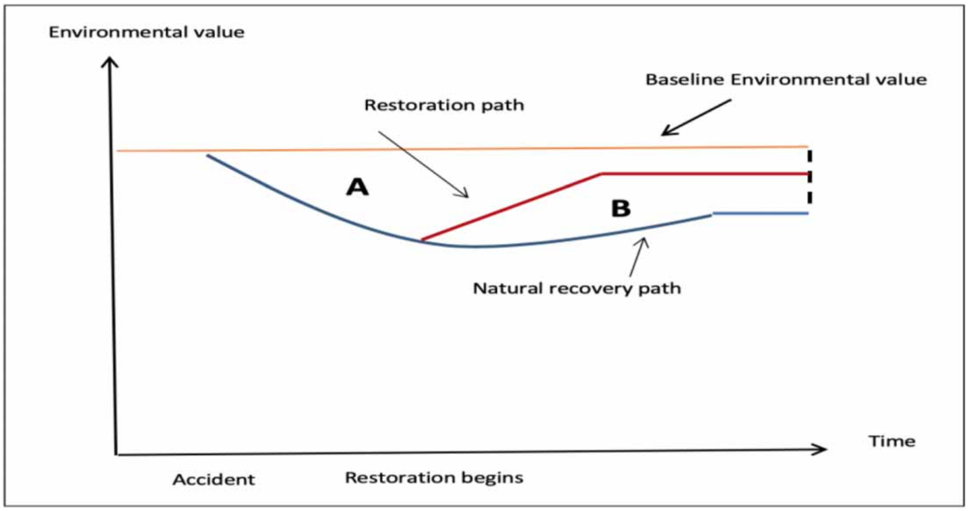

Fig. 2. Schematic presentation of combined cost of damage reduction and restoration (adapted from Dunford *et al*., 2004 and Pioch *et al*., 2017). Please refer to the online version of this paper to see this figure in color: http://dx.doi.org/10.2166/wp.2020.014.

where $\text{Damage}_{\text{nr}}$ is the present value of damage under the natural recovery process, D_t is damage at year *t*i NR_t is natural recovery shares out of the initial damage, *r* the discount rate, z the rate of natural recovery, and *T* is time.

The result of Equation (1) is simply the present value of yearly damages weighted by the recovery process. Active restoration efforts, on the other hand, result in the following discounted value of damage:

$$\text{Damage}_{\text{ar}} = \sum_{t=0}^{\infty} (D_t(1 - \text{NR}_t - \text{AR}_t)/(1 + r)^t) \tag{2}$$

where $\text{Damage}_{\text{ar}}$ is the present value of damages under active restoration and AR_t is the additional share of damage reduction due to active restoration efforts.

The restoration cost is given by:

$$\text{Cost}_{\text{ar}} = \sum_{t=0}^{\infty} (\text{CAR}_t/(1 + r)^t) \tag{3}$$

where CAR_t is the yearly cost of the restoration effort and Cost_{ar} is the present value of the total restoration efforts.

The total cost of restoration process is a combination of Equations (2) and (3). The difference between Equation (1) and Equations (2) and (3) is that the ratio in Equation (2) decreases because the numerator becomes smaller as a result of the restoration. Equation (3) stands for the added cost of the restoration (this term CAR was assumed zero in Equation (1)).

The CBA is thus an empirical question regarding the difference between Equation (1) and the sum of Equations (2) and (3). If the former is greater than the latter, the restoration effort was effective; otherwise, it was not. The payment paid by the polluter should be equal to the smaller of the two values.

Our benefit estimation, which will be described later, dealt with the area A + B – the value of the damage or the benefit of preventing such damage. The issue of saving the cost of B through active restoration is another case of asking whether the cost of such a path is worthwhile compared to the reduction in time required to reach (near) full rehabilitation[3].

3.2. Damage assessment

Since ephemeral streams are natural assets, their value can be assessed as the benefit of a well-functioning ecosystem to society (Bergstrom & Loomis, 2017). However, since there is no well-defined market for these ecosystem services, a non-market valuation method must be used. CV is one of the only methods that can estimate non-use value[4], which is particularly significant for such isolated environmental assets (Carson *et al*., 2001; Lee, 2012; Kaffashi *et al*., 2015; Vásquez & de Rezende, 2018; Becker *et al*., 2019).

The National Oceanic and Atmospheric Administration (NOAA) panel (Arrow *et al*., 1993) recommends dichotomous choice as the preferred model because it complies the most with incentive compatibility and with how individuals act in real life. Dichotomous choice was used in both non-parametric and parametric ways, complemented by use of a payment card method to refine the results and to check for robustness.

In the dichotomous choice method, individuals say ‘yes’ or ‘no’ to a given tax that might hypothetically be imposed on them and that is intended to lead to environmental improvement. An individual should say ‘yes’ if the benefit to him or her of restoring the ecosystem is greater than the personal cost of the hypothetical tax: P(yes) = P(WTP > bid), where WTP stands for *willingness to pay*. This approach allowed us to derive WTP estimates from econometric models of binary responses.

To estimate the mean WTP for the prevention program, a non-parametric survival model of the data was firstly used. This non-parametric WTP estimate is free of any functional form. The Turnbull (1976) estimator was applied which is a non-parametric estimator suitable for grouped, censored and/or truncated data. The Turnbull distribution has been used in many contingent valuation studies (e.g., Haab & McConnell, 1997) and has been shown to provide a straightforward alternative to parametric models for estimating mean WTP.

The assumption underlying the analysis is that a respondent is considering a bid B which lies in the interval I_j to I_{j+1}; that j is indexed as $j = 0, 1, \ldots, N$; and that $I_j > I_k$ for $j > k$. We let P_j be the probability that the respondent's WTP is in the interval I_{j-1} to I_j. Previous studies that used the Turnbull distribution (e.g., Hutchinson *et al*., 2001) assumed that the true distribution function is piecewise linear between the point estimates of the empirical distribution function and that such a distribution has an arbitrary upper

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[3] Let us define some of these similar-sounding words. By *restoration* we mean a deliberate (human) effort to return the area to an earlier, healthier, ecological state. *Recovery* is what the system can achieve without human help, while *rehabilitation* is the intended goal of restoration.

[4] An alternative approach is to estimate the value of the prevented damage with the choice experiment method. This has the benefit of estimating the values of partial restoration options, as considered later. However, dealing with individual options for eight different sections was very confusing to the focus groups, so we decided to continue with the CV method.

bound. Thus, in this work the mean lower-bound WTP for the prevention program was given by:

$$E(\mathrm{WTP}) = \sum_{j=0}^{N} t_{j-1} B_j \tag{4}$$

Replacing the bid that the respondent is asked about by the lower bound of each interval, a lower-bound estimate of WTP was obtained. This estimated lower-bound WTP was an asymptotically normal distribution, because it is a linear combination of the values of P_j, which were themselves asymptotically normal.

In a parametric framework, responses to the bid question were investigated through logit models:

$$\ln[P_Y/(1-P_Y)] = \beta_j(Z) + \beta_{\text{price}}(B) + \varepsilon \tag{5}$$

where P_Y is the probability of a yes answer, Z is a vector of socio-demographic and scenario characteristics, B is the bid amount, β_j and β_{price} are the regression coefficients of the associated variables, and ε is an error term.

The mean WTP was estimated using Hanemann *et al.*'s (1991) formula:

$$\text{mean WTP} = \frac{\text{Const.} \; + \sum_{1}^{J-1} \beta_j \bar{Z}}{\beta_{\text{price}}} \tag{6}$$

The payment card method presents respondents with a card with different amounts written on it and asks them to circle the amount that is the most they would be willing to pay (Cameron & Huppert, 1989). For the econometric analysis, a Tobit model was used (Tobin, 1958). This method reduces the problem which appears in standard ordinary least squares linear regression when many zeros are accumulated. In such cases, it is better to restrict the dependent variable around a certain value (see e.g., Halstead *et al.*, 1991). The model specification is given by the following censoring rule:

$$y_i = \{y_i^*, \;\text{ if } y_i^* > 0, \;\; 0\,\text{otherwise}) \tag{7}$$

where y_i is the stated WTP of respondent i. That is, if the calculated WTP for a given respondent would be negative, it is instead set to zero.

3.3. Restoration costs

A combination of several methods to calculate the costs of proactive rehabilitation were used. In some cases, pollution can be treated and removed by soil exchange, or by using flowing water to wash away the contaminants. If plants and animals were destroyed, the cost of replacement was used (e.g., the cost of raising and rehabilitating animals, removal of damaged vegetation, and planting of compatible vegetation). If resources used by people, such as groundwater, were affected, the cost of purchasing and transporting those resources was employed. In addition, costs of monitoring, maintaining and managing the reconstruction project were estimated. This was based on expert assessement from the Nature

Protection Agency to represent the probability and magnitude of success in reducing the damage over time[5].

4. Calculations

4.1. Restoration cost

Possible restoration activities on the ephemeral stream span several natural ecological units (habitats) with different geomorphology and flora: dune unit, dune rock unit, shallow and deep units, lower alobia, shifting channel, Northern Ashalim Reservoir and Southern Ashalim Reservoir. A different restoration program would be required for each section.

4.2. Path of active restoration

Proactive restoration activities can lead to faster recovery of the damage and, in some cases, a better state than natural recovery could achieve. Table 1 shows the main restoration activities for each segment with the period of implementation and the (expected) resulting level of rehabilitation.

In most segments of the stream, it will not be possible to reach full rehabilitation even with proactive restoration. The advantage of proactive restoration is quicker recovery than occurs with a purely natural process. It is projected that proactive restoration could achieve significant rehabilitation in only one year.

4.3. The contingent valuation survey

Elicitation of WTP requires an appropriate survey design and sample selection (Bateman *et al.*, 2002). Such surveys have two main parts: a hypothetical scenario that introduces an environmental change, and a question that elicits respondents' maximum WTP for that change (Birol *et al.*, 2006).

The questionnaire design was pretested on two occasions in March 2018 by asking an open WTP question in face-to-face interviews. This process gave us a range of bids to use for both the dichotomous choice question and the payment card. We also received constructive comments on the mode of payment to minimize protest responses.

Eight versions of the survey were used to test for scope and price sensitivity. Price sensitivity was tested via a closed-bid question, using prices in Israeli shekels (ILS 75, 150, 400, and 600)[6]. The scope test was performed using the method of Bishop *et al.* (2017): Each price was presented using two different descriptions of the problem. The first version was accompanied by a restrained verbal description of the damage. The second group received a more dramatic story, which emphasized the severity of ecological damage, which was also represented in the photographs of the damage this group was shown.

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[5] The district ecologist and chief scientist of the NPA.

[6] ILS 1 = € 0.23 or USD 0.27. These prices were based on the range of answers in pretest focus groups.

Table 1. Restoration actions by stream section.

Segment	Action	Years of rehabilitation	Expected rehabilitation success over time[a]
Dune unit	Soil replacement	1	Replacing 5% of the soil will remove some pollutants and lead to the rehabilitation of 40% of the ephemeral stream after one year, while 60% remained damaged.
Dune rock unit	Soil replacement	1	Replacing 5% of the soil will remove some pollutants and lead to the rehabilitation of 40% of the ephemeral stream after one year, with 60% remaining damaged.
Shallow and deep units	Water flushing	5	Water flow will restore 40% (of the damage) after one year. Combined with a large natural flood, the effects of the damage are expected to disappear in five years.
Lower alobia	Soil replacement	1	Replacing 5% of polluted soil will remove some pollutants and lead to the rehabilitation of 40% of the ephemeral stream after one year, with 60% remaining damaged.
Shifting channel	Soil replacement	1	Replacing all polluted soil in the section will remove pollutants and lead to the rehabilitation of 80% of the stream after one year, with 20% remaining damaged.
Northern Ashalim Reservoir	Soil replacement	1	Replacing all polluted soil in the section will remove pollutants and lead to the rehabilitation of 80% of the stream after one year, with 20% remaining damaged.
Southern Ashalim Reservoir	Rehabilitation of water quality plus hydrological rehabilitation of groundwater	1	Focus on preventing leakage of pollutants into the reservoir when a large flood (expected every 10 years) occurs.

[a] This column refers to the level of rehabilitation that can be achieved with the specified action. When the level of rehabilitation is 60%, the qualitative assessment of environmental damage remains 40%.

The first section comprised a description of the ephemeral stream and the accident. This was followed by photographs. Following Carson *et al.* (2003), pictures of dead animals were excluded from the survey to avoid extreme answers. The restrained description was:

> ‘*The accident which happened in June 2017 flooded the ephemeral stream with 100,000 m^3 of acid waste. This, in turn, caused harm to fauna and flora. Part of the ephemeral stream remains polluted, and it is currently closed to visitors. Natural floods may dilute the pollution and might solve part of the problem.*’

The dramatic description was:

> ‘*The accident which happened in June 2017 caused a flood of the ephemeral stream with 100,000 m^3 of acid waste. This had an immediate effect, killing vegetation and animals. The ecological function of the ephemeral stream was severely degraded. All types of vegetation that came in contact with the acid were scorched. About 70% of the vegetation has not recovered, and it is not clear if it ever will.*

> *Pumping of the polluted water, together with evaporation, caused the polluting materials to sink into the soil, and this may be a future source of pollution in the next flood. The ephemeral stream is closed to travelers, and it is not clear when it will be reopened.*'

The second section comprised valuation questions regarding the environmental damage. As in Carson *et al.* (2003) and Loureiro *et al.* (2009), this section mentioned the possibility of a future accident of the same kind if no preventive measures are put in place. No specified probability was discussed for such an accident but a fifteen-year time frame was mentioned. Within this time frame, the program would prevent a similar accident. Respondents were asked whether they would be willing to pay a one-time special tax to implement measures to prevent another such accident in the next 15 years. This was specified as an addition to their overall current tax payment, following comments we received from initial focus group participants. We are aware of other payment methods, including paying for services by shifting taxes from other uses (Barak & Katz, 2015). Following the closed bid of one of the four options mentioned above, there was a follow-up payment card question, which was based on a similar card for all versions.

Before asking the respondents to answer the payment question, respondents were asked to read several 'cheap talk' statements:

> '*We ask you to be sincere and answer like this is a real decision, although it is not. We want you to consider that you would like to protect the environment, but that this would mean less money available for other things that are also important.*
>
> *On the other hand, we would like you to remember that the program will not be implemented unless most Israeli taxpayers agree to contribute to this fund.*
>
> *We would like to stress that the question we are asking is solely about the value of restoration. Try to ignore the issue of who the blame should fall on, because this issue is to be solved in another arena.*'

The third section comprised socio-demographic questions to investigate how economic theory was embodied in the other responses. The variables were gender, age, number of people in the household, place of origin, education, membership in a green (environmental advocacy) organization, and income.

Since the accident was a major news event, a representative sample was required of the whole national population of Israel. A professional survey company was hired in order to elicit answers from 2364 individuals who formed a representative sample of the Israeli population in April 2018.

5. Results

We present the results of the restoration costs of the proactive restoration, the benefit from the restoration (the deprivation of the damage), and the net benefit that equals the combination of the cost and benefits.

5.1. Proactive restoration cost

A summary of the costs associated with proactive restoration of the different river segments is given in Table 2. The expected cost for the relevant year for each action is presented, starting with the first year

Table 2. Dynamic of active restoration plan (all amounts in ILS millions).

Actions	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
General rehabilitation activities										
Restoring immediate damage (supervision, samples, etc.)	0.63									
Management, inspection and security	0.31	0.31	0.31	0.31	0.31					
Ecological research and monitoring program	0.11	2.50	2.50	2.50	2.50	2.50				
Risk survey and soil survey		1.11	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Rehabilitation of the ibex population		2.09	1.60	1.42	0.83					
Rehabilitation of desert vegetation		6.68	0.87	0.87	0.20	0.20				
Treatment of acacia trees (irrigation)		0.49	0.05	0.05	0.05	0.05				
Specific restoration activities in the different sections of the ephemeral stream										
Dune unit: Treatment of contaminated soil and hydrological rehabilitation of groundwater		3.06	0.90	0.90	0.90	0.90				
Dune rock unit: Treatment of contaminated soil		0.97								
Shallow and deep units: water flow		14.66								
Lower alobia unit: Treatment of contaminated soil		1.47								
Displacement canal: Treatment of contaminated soil		53.21								
Northern Ashalim Reservoir: Treatment of contaminated soil		83.47								
Southern Ashalim Reservoir: Improving water quality and hydrological rehabilitation of groundwater		3.50	0.73	0.73	0.73	0.73				
Total restoration costs	**1.05**	**173.50**	**7.75**	**7.58**	**6.31**	**5.18**	**0.80**	**0.80**	**0.80**	**0.80**
Total capitalized capital cost[a]	**1.05**	**173.50**	**7.52**	**7.14**	**5.78**	**4.60**	**0.69**	**0.67**	**0.65**	**0.63**

[a] In order to show the total costs of the restoration in present value terms, we performed capitalization of all the years at a capital price of 3%.

of restoration (2017) and continuing through the entire ten-year restoration program. The upper part of the table describes the general activities that are not related to a specific section of the ephemeral stream; these include activities such as immediate restoration efforts, inspection and security, ecological research and monitoring programs and restoring vegetation. The lower part of the table specifies activities unique to each segment.

Most actual restoration in this plan occurs in its second year, because the first year was assumed to mainly involve planning and preparation. It would then be possible to execute most of the activities and invest in infrastructure in the second year. In the following years, most of the cost is projected to be for current operations. All annual values were discounted at 3% to get a present value of ILS 201.425 million.

5.2. Damage assessment

The damage assessment is based on results derived from the representative sample. In this section, descriptive statistic, econometric results and the derived value of the damage (or damage reduction) are presented below. Table 3 summarizes the variables gathered from the surveys.

Table 3. Descriptive statistics.

Variable	Mean	Std. Dev.	Min	Max
Heard before	0.48	0.5	0	1
Payment card (ILS)	149.2	212	0	1,000
Gender	0.55	0.5	0	0
Age (years)	39.9	13.9	18	77
Persons in household	3.67	1.71	1	14
Origin (Israelis = 1)	0.86	0.35	0	1
Education (1–5)	3.36	1.07	1	5
Green (Green = 1)	0.11	0.31	0	1
Income (1–5)	2.65	1.13	1	5

Of the 2,364 respondents, 55% (1,300) were women. There were 3.67 people per household on average, and 86% of respondents were native Israelis. The average education level was 3.36 out of 5, average income was 2.65 out of 5[7], and 11% of respondents reported an association with a ‘green’ organization. All these variables were in line with the statistical profile of the nation, except gender. However, since the gender skew was not significant, no correction for this small bias was applied.

Forty-eight percent of the respondents had previously heard about the accident. The mean WTP from the payment card was ILS 149. Table 4 gives the number of respondents that answered each version of the survey for each bid amount. We aimed for 350 responses for each version (for a total of 2,800) and collected a total of 2,364 full response surveys.

The probability of yes responses is summarized in Table 5. Since the eight versions (combinations of bid amount and dramatic vs. restrained description) were created to test the price and scope effects, it is important to look at the differences among the rows and between the columns. The dramatic version induced higher probabilities for all bids, but the difference was significant only for the ILS 75 bid. Looking at each column reveals that, for each version (dramatic or restrained), the probability of yes responses fell significantly as the bid rose.

Three estimation results are reported below: a parametric analysis, logit regression for the parametric dichotomous choice model, and Tobit regression on the payment card model. It should be noted again

Table 4. Distribution of respondents by versions of the survey.

Bid	Dramatic version	Restrained version	Total
75	295	286	581
150	272	327	599
400	309	315	624
560	301	259	600
Total	1,229	1,135	2,364

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[7] The five education levels were high school, technical school, first degree, second degree, and Ph.D. The five income levels were well below average, below average, average, above average, and well above average.

Table 5. Probability of yes response by bid and version.

Bid (ILS)	Dramatic version	Restrained version
75	0.58 (±0.06)	0.49 (±0.06)
150	0.48 (±0.06)	0.46 (±0.06)
400	0.28 (±0.05)	0.26 (±0.05)
600	0.22 (±0.05)	0.20 (±0.05)

Note: Number in parentheses indicates a 95% confidence interval around the mean.

that the payment question was about a similar accident happening within the next 15 years. To be conservative, we assumed that the accident would happen *after* 15 years. Equation (8) connects that one-time payment to annual WTP:

$$\mathrm{PV(Benefit)} = \frac{\mathrm{Year\_B}}{r}\left(1 - \frac{1}{(1+r)^T}\right) \tag{8}$$

Here the left-hand side stands for the one-time payment, where Year_B is the derived annual payment, r is the discount factor (3%), and T (=15) stands for the time in years.

To perform the non-parametric test, probabilities and cumulative probabilities were calculated for the dramatic and restrained versions (Table 6).

Non-parametric results. Two calculations are reported: The first one weights the probability of a yes response for each interval of two adjacent bids. The second normalized all the probabilities of a yes response so the sum is equal to 1, and then weighted the bid in every such probability. Clearly, the first calculation is the conservative one. The results for both the dramatic (Table 7) and restrained (Table 8) versions are reported below.

For additional calculations and in order to be on the safe side, only the minimum value of the restrained version, ILS 37.19 million annually, is used.

Parametric analysis based on the dichotomous choice. Only the Logit estimates (Table 9), since the Probit results were similar and slightly less significant. All variables except gender and persons per household were significant.

Using Hahnemann's equation (Hanemann *et al.*, 1991) for the mean value, the numerator in the right-hand side is the sum of the constant and all mean values of the explaining variables multiplied by their derived coefficients besides the bid. The denominator is the bid coefficient. By substituting the values of the

Table 6. Cumulative and non-cumulative probability of yes response.

	Dramatic version		Restrained version	
Bid (ILS)	Non-cumulative probability	Cumulative probability	Non-cumulative probability	Cumulative probability
75	0.37	1	0.35	1
150	0.31	0.63	0.33	0.65
400	0.18	0.32	0.18	0.32
600	0.14	0.14	0.14	0.14

Table 7. Non-parametric results for the dramatic version.

Bid (ILS)	75	150	400	600	One-time payment	Annual payment for a household (ILS)	Annual national value (ILS millions, for 2.47 million households)
Difference	75	75	250	200			
Pr (yes)	0.58	0.48	0.28	0.22			
Weighted Pr	0.37	0.31	0.18	0.14			
Minimum value	43.5	36	70	44	193.5	16.21	40.04
Mean value	27.9	46.15	71.8	84.6	230.45	19.3	47.7

Table 8. Non-parametric results for the restrained version.

Bid (ILS)	75	150	400	600	One-time payment	Annual payment for a household (ILS)	Annual national value (ILS millions, for 2.47 million households)
Difference	75	75	250	200			
Pr (yes)	0.49	0.46	0.22	0.20			
Weighted Pr	0.34	0.32	0.20	0.14			
Minimum value	36.75	34.5	72.5	40	181.25	15.18	37.19
Mean value	25.7	48.25	78.3	83.9	237.3	19.9	49.15

mean for the variables from Table 8 and the coefficients from Table 9, Equation (9) below is obtained:

$$\text{mean WTP} = \frac{\text{Const.} + \sum_{1}^{J-1} \beta_j \bar{Z}}{\beta_{\text{price}}} = \frac{-0.463 + 0.331}{-0.000853} = 154.5 \tag{9}$$

Remembering that ILS 154.5 million represents a one-time payment, Equation (1) to convert that value into annual payments and then multiplied that by 2.47 million households. The results can be translated into ILS 13.1 per household and ILS 32.2 million for the entire nation.

Payment card results. The payment card was filled with numbers from 0 to ILS 1,000. The mean WTP was ILS 149 (Table 4), with a standard deviation of 212 (Table 3). The same explaining variables as in the Logit model were significant. Again, only people per household and gender were insignificant; all others were significant and possessed the expected sign.

The mean WTP of ILS 149 is a one-time payment for 15 years. Again, Equation (1) to find the annual payment and multiplied it by 2.47 million households, in this case, yielding ILS 12.5 per household and ILS 30.85 million for the entire nation. Table 10 summarizes the WTP results for the three models. The mean value of the three estimates was considered to minimize the potential biases of each one.

5.3. Combining restoration cost and damage reduction

In this section, the results of the CBA are reported by combining the costs of proactive restoration with its benefits (reduction of damage), resulting in a net benefit for proactive restoration. The calculations of the benefits used the proportionate share of the redaction in the damage according to the

Table 9. Logit and Tobit regression estimation.

	Logit		Tobit	
	Coefficient	P	Coefficient	P
Price	−0.000853	0.00***		
Heard before	0.22	0.00***	52.1	0.00***
Green	0.25	0.01*	56.5	0.01*
Gender	0.005	0.89	10.3	0.25
Age	−0.0093	0.00***	−3.17	0.00***
Persons in household	0.00018	0.988	−3.71	0.158
Education	0.0824	0.00***	28.1	0.00***
Income	0.0819	0.00***	19.2	0.00***
Intercept	−0.463	0.00***	30.2	0.00***
	$N = 2{,}364$		$N = 2{,}364$	
	LL = −2,914.3		LL = −23,494.509	
	Pseudo-$R^2 = 0.31$		Pseudo-$R^2 = 0.38$	
	LR $\chi^2(7) = 190.37$***		LR $\chi^2(7) = 178.42$***	

*, **, ***significant at 90%, 95%, and 99%, respectively.

Table 10. Summary of willingness-to-pay results from the three models.

Method	One-time payment (ILS)	Annual payment per household (ILS)	Annual payment for the nation (million ILS)
Non-parametric	181.25	15.18	37.2
Probit	154.5	13.1	32.2
Tobit	149	12.5	30.85
Mean	161.6	13.6	33.2

level achieved by proactive restoration in each year (according to Table 1). To estimate the benefits, the partial value of the total damage weighted by the size of the relevant section of the ephemeral stream.

The results are presented in present value terms and compared to the alternative of relying on the natural recovery process – that is, the relative benefits of proactive restoration and natural restoration are compared. Table 11 presents (for each stream segment) the annual damage (column 3), the net benefit of proactive restoration compared to natural restoration (column 6), the cost of proactive restoration (column 7) and the net benefit (benefit minus cost). Evaluating each segment separately allowed us to identify the optimal route of action – identifying which segments should undergo proactive rehabilitation and which should be left to natural restoration.

All these results were based on calculations according to Equations (1)–(3). Annual adjusted damage (column 3) is contingent valuation (ILS 33.2 million per year) multiplied by the relative area of each segment. Present value with active restoration (column 4) is the total remaining damage after the active rehabilitation actions are carried out. For example, the value for the first segment is $\mathrm{PVI} = 6.4 + [0.6 \times (6.4/0.04)/1.03] = 98.2$. That is, full damage in the first year and then 60% of the discounted remaining damage (which is discounted one year back).

Table 11. Current values of ecological damage when restoration programs are implemented.

(1) Segment	(2) Relative part of the area (%)	(3) Annual adjusted damage (ILS millions), D_t	(4) Present value with active restoration (ILS millions), $\mathrm{COST}_{\mathrm{PR}}$	(5) Present value without active restoration (ILS millions), $\mathrm{COST}_{\mathrm{NR}}$	(6) Difference between natural and active restoration efforts, (5) – (4)	(7) Present value costs of all active restoration actions	(8) Net benefit, (6) – (7)
Dune unit	19%	6.31	98.2	157.7	59.5	6.4	57.3
Dune rock unit	7%	2.32	36.1	58.1	22.0	0.97	23.3
Shallow unit	8%	2.66	7.39	11.1	3.71	14. 6[a]	– 2
Deep unit	2%	0.8	2.22	3.5	1.28		
Lower alobia	11%	3.65	56.3	91.3	35.0	1.46	34.7
Shifting channel	11%	3.6	21.1	88.8	67.7	53.2	15.7
Northern Ashalim Reservoir	17%	5.64	33.0	141.1	108.1	83.5	25.2
Southern Ashalim Reservoir	25%	8.3	0[b]	207.5	207.5	6.2	201.3
Total (rounded to the closest million)	**100%**	**33.2**	**254.1**	**759.1**	**504.8**	**151.7**	**355.5**

[a] The rehabilitation activity initiated in this section (water flow) is carried out without distinction between the shallow and deep units.

[b] If the preventive actions are carried out, it is possible to prevent any damage to the specific segment.

Present value without active restoration (column 5) is damage for each part discounted at 4% (=3% +1%). Column 6 is the difference in the remaining damage between natural and active restoration efforts. The present value of the total active restoration actions (column 7) is the sum of all active restoration actions. Net benefit is the difference between columns 7 and 8.

Overall damage following natural restoration was estimated to be higher than under proactive restoration, by ILS 504.8 million in present value terms. Since the cost of the overall restoration is ILS 151.7 million, the project in general passes the cost–benefit test, with a net benefit of ILS 355.5 million. The responsible party would be liable for ILS 405.8 million (151.7 + 254.1).

Since different sections can be managed (be opened or remain closed) independently, it was also important to examine the different segments of the ephemeral stream to consider partial restoration options (Becker *et al.*, 2019). To do that, we examined column 7 in Table 11 for information on the marginal costs of each of the eight segments. This enabled column 8 to be created, the net benefit of restoring a given section. The total net benefit for active restoration of all segments is ILS 355.5 million.

6. Discussion

Economic valuation seems to add a substantial value to the common methods of environmental impact assessment (Crookes & de Wit, 2002). In this work, we performed such an analysis to demonstrate how it can form a basis for damage valuation following ecological accidents. Our non-market valuation used a CV approach.

The results in this case show a clear net benefit for restoring the ephemeral stream. In both the logit and tobit regressions, the same variables are significant (9), and all have the expected sign. Respondents who had heard about the accident before, identified as ‘green,’ were more educated, had higher incomes, or were younger were willing to pay more for active remediation (or the probability of their saying yes to a specific bid was higher). Only two variables were insignificant: people per household and gender.

In this work, our conclusions are empirical and based on a detailed cost analysis for the different sections of the ephemeral stream and the benefits of restoring them. We are aware that other versions of CBA could be applied, such as multi-criteria analysis, where the emphasis is on different ecosystem services trade-offs, participation issues (Zoppi, 2007; Alam, 2013), or a more probabilistic approach to the success of restoration (Martínez-Paz *et al.*, 2014). The type of description of the damage shared with respondents are important factors that affect the results (Bliem & Getzner, 2012). It is conceivable that future studies could find that recovery may be left to natural processes, eliminating the need for human intervention, although we found no such examples in the literature.

Becker *et al.* (2019) demonstrated that in the case of the Kishon ephemeral stream in Israel, partial restoration yielded a higher net benefit than full restoration. In both Becker *et al.* (2019) and the present case, it is appropriate to analyze partial restoration only if the different areas can legitimately be considered independent projects. There is no meaning in dividing a basin into sections if decisions cannot be made independently for the different sections. Partial analysis also depends on splitting the restoration costs into fixed and variable costs. The net benefit should be considered only when subtracting the variable cost from the benefit of that section, while fixed costs should be set aside and only later compared with the total net benefit for all sections.

7. Conclusions

Most decisionmakers in developed countries currently choose to perform proactive restoration for ecological damage. However, there is often reluctance to make the required investment when it turns out that rehabilitation will be costly. Using a CBA tool allows comparison of damage and benefit in financial terms. Even if the cost of proactive rehabilitation is high, the value of the damage avoided can be measured and may justify that cost.

To accurately perform such analyses, the cost of proactive rehabilitation must be compared to the benefit of reducing the expected damage over time. However, in the analysis of damage, the reduction in damage resulting from pro-active restoration should be compared with the effects of natural restoration over time. Only in cases where the benefit of proactive rehabilitation exceeds the cost is restoration appropriate.

The benefit of rehabilitation should be measured for the relevant population. In our case, all residents of Israel are the relevant target audience, whether they visit the river or not. This is because of the significant non-use value of the Ashalim stream. That is, although a large portion of the population is unlikely to visit the creek in the coming years, they still provide a (non-use) value for the damage caused by the accident. The contingent valuation analysis presented here follows previous studies but is the first to consider damage valuation for a significant accident in Israel.

Economic valuation has a role to play in the inclusion of human welfare considerations in damage and compensation measures. Stated preferences techniques also allow consideration of non-use values and preference heterogeneity, as demonstrated in this study.

Often, ‘non-users’ are not considered in policy deliberations, but non-use values may comprise an important portion of a natural resource’s total economic value (O’Neill & Spash, 2000). Therefore, the method used in this work may help policymakers and decisionmakers determine the contribution of this value component to a resource’s total economic value when choosing a remediation option.

Notably, our empirical results should be useful to the Israeli government in reaching a financial settlement with the responsible polluter in this case. Other countries may find our empirical results useful as a starting point for calculating preliminary monetary damages following similar accidents in arid regions until site-specific studies can be completed.

The study is not free from limitations. We assumed that the partial benefits of the different sections are proportional to the size of that section. Of course, ecosystem services are not solely a function of the size of the affected area, but more careful analysis would require eight individual studies. Another limitation concerns the information lost due to the use of only a nationally representative survey as opposed to visitors only. Another approach would be to concentrate on use value through a travel cost study, as done by Whitehead *et al.* (2018) for the Deepwater Horizon disaster. However, in our case, the ephemeral stream was (and at the time of writing, remained) closed, so it was impossible to study visitor behavior through the lens of travel cost.

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Received 18 January 2020; accepted in revised form 6 April 2020. Available online 15 May 2020