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Mitigating infrastructure loss from beaver flooding: A cost–benefit analysis

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ABSTRACT
We installed 12 pond levelers to counter flooding by beavers and developed a cost–benefit analysis for these sites in Alberta, Canada. We also documented beaver management approaches throughout Alberta. Over 3 years, one site required regular maintenance until we designed a modified pond leveler; another required minor modifications. Others required almost no maintenance. Based on a "willingness-to-pay" (WTP) of $0 and discount rate of 3%, installing pond levelers resulted in a present value net benefit of $81,519 over 3 years and $179,440 over 7 years. Scenarios incorporating discount rates of 3% and 7%, horizons of either 3 or 7 years, and varying WTPs resulted in significant net benefits. Provincially, municipalities employed up to seven methods to control beavers: most commonly lethal control and dam removal. Total annual costs provided by 48 municipalities and 4 provincial parks districts were $3,139,223; however, cost-accounting was sometimes incomplete, which makes this a conservative estimate.

KEYWORDS
beaver; cost–benefit analysis; environmental economics; wetland loss

Introduction

Global declines in wetlands range from 30% to 90%, depending on jurisdiction (Junk et al., 2013), and highlight the need for improved policies and management strategies. Despite efforts to reduce wetland loss in North America, historic and current industrial, urban and agricultural developments have resulted in dramatic declines in the number and size of wetlands (Bedford, 1999). Harper and Quigley (2005) determined that urban development and roads accounted for much of the loss of fish habitat in Canada and restoration success was inconsistent and poorly documented. A less studied phenomenon is the degree to which routine management actions, such as the regular removal of beaver dams to reduce human–wildlife conflict, contribute to permanent or intermittent wetland loss.

Removal of dams, coupled with local extirpation of beaver colonies, results in an immediate and repeated loss of wetlands that are not only high in biodiversity (Hood & Larson, 2014; Law, McLean, & Willby, 2016; Wright, Jones, & Flecker, 2002), but also have greater resilience to drought (Hood & Bayley, 2008; Hood & Larson, 2015), important connections to groundwater recharge (Westbrook, Cooper, & Baker, 2006), and higher storage potential than other wetlands in the same area (Hood & Larson, 2015). Despite

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their effects on the biotic and abiotic environment, specific valuation of beaver-modified wetlands is rare.

More generally, valuation of "ecological goods and services" of natural inland wetlands in US$ can range from $3,018 to $104,924 per hectare^{-year} (Costanza et al., 2014). Restored or created wetlands that serve as compensation provide hydrological and ecological functions, (Zedler & Kercher, 2005), but costs can be prohibitive and ecological effectiveness variable (Ruhi, Boix, Gascón, Sala, & Quintana, 2013). Wetland policies in Alberta, Canada, stress the need for "no net loss" (Harper & Quigley, 2005; Rubec & Hanson, 2009), especially in the context of climate change (Erwin, 2009; Schindler & Donahue, 2006). The agencies tasked with enforcement of these policies (e.g., provincial and federal parks services, fish and wildlife agencies), however, are often the ones removing beaver-maintained wetlands on a regular basis (Bergstrom et al., 2014; Taylor & Singleton, 2014). Short-term management of flooding by beavers can take precedence over long-term ecological benefits of these wetlands (Boyles & Savitzky, 2008; Taylor & Singleton, 2014).

Nonlethal methods to reduce damage caused by flooding are not new (Laramie, 1963; Taylor & Singleton, 2014); however, draining of beaver impoundments and removal of the colony remain commonplace (DeStefano & Deblinger, 2005; Mensing, Galatowitsch, & Tester, 1998; Siemer, Jonker, & Brown, 2004), despite economic and ecological costs. Compensation to trappers and facility repairs (e.g., culverts, trails, and roads) can account for $125,000 per year and $4,900 per incident, respectively (Jensen, Curtis, Lehnert, & Hamelin, 2001; Mensing et al., 1998). In many cases, however, these costs are poorly documented and outdated (Mensing et al., 1998). Alternative management methods, such as the use of pond-leveling devices, are receiving increased attention and have shown positive results in follow-up programs (Jensen et al., 2001; Lisle, 2003; Nolte, Swafford, & Sloan, 2000). With these devices, a pipe system is installed in an existing beaver dam or chronically plugged culvert (Figure 1). The pipe is placed at the same height through the dam as the desired water level in the waterbody. Whenever the water rises above that height, water draws through the pipe until water levels return to the desired height. The end of the intake is protected by a metal cage and is placed approximately 6–10 m from

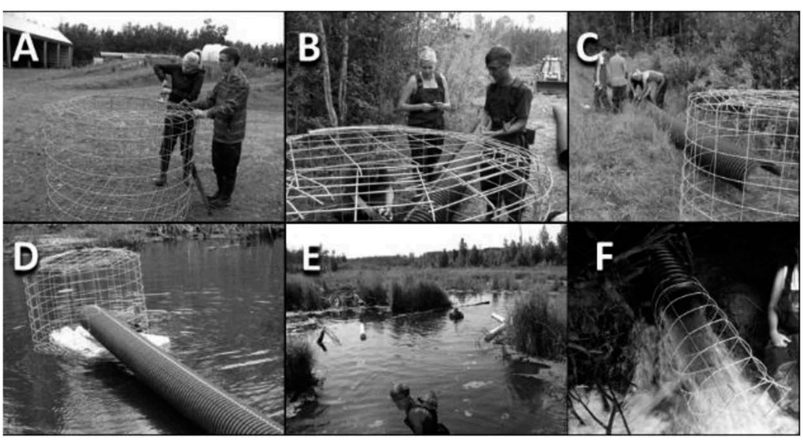

Figure 1. Pond levelers.

the dam. Maintenance of the devices is important for success (Nolte et al., 2000), and when maintained they can result in overall cost savings (Boyles & Savitzky, 2008).

Although these structures are used in many areas, the extent of their general adoption is unknown and follow-up studies as to the efficacy of pond levelers, such as the Beaver Deceiver™ (Lisle, 2003) and Clemson beaver pond levelers (Nolte et al., 2000), are rarely studied. The same applies to commercially available products and culvert fence designs. With urban encroachment into natural areas, human–beaver conflicts are increasing and creative solutions are required to reduce conflicts, while still accommodating public demands for adaptive wildlife management (DeStefano & Deblinger, 2005; Jonker, Muth, Organ, Zwick, & Siemer, 2006). To address these deficiencies, our objectives were to (a) install and assess the efficacy of pond-leveling devices and specialized fencing in areas with chronic flooding, (b) develop a cost–benefit analysis for these sites to quantify the cost differential between existing ("traditional") management approaches (e.g., trapping, hunting, dam removal using backhoes or explosives) and alternative approaches (i.e., pond levelers, commercial devices, and specialized fencing), and (c) quantify province-wide approaches and costs for beaver management in Alberta in an attempt to extrapolate aspects of the cost–benefit analysis to a provincial scale. This combination of fine- and broad-scale analyses provides insight into economic and operational realities of human–wildlife management at multiple scales.

Methods

Study Area

This article focused on the efficacy of pond levelers and cost–benefit analyses within a provincial protected area east of Edmonton, Alberta. The Cooking Lake/Blackfoot Provincial Recreation Area (CLBPRA) lies within the heart of the Cooking Lake Moraine in east-central Alberta, Canada (Figure 2). The 97 km^2 park lacks any large rivers or streams; however, kettle wetlands cover the landscape. As part of the southern dry mixed-wood boreal forest, trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balasmifera*) are the dominant tree species. Despite their extirpation in the mid- to late 1800s (Hood & Bayley, 2008), beavers are common throughout the park.

The CLBPRA is also a popular destination for recreationalists (e.g., equestrians, hikers, Nordic skiers) and is a public grazing reserve for cattle. There is a limited number of oil and gas well sites within the park. Although under the protection of Alberta Parks as a provincial recreation area and grazing reserve, the park's multiuse mandate has resulted in over 170 km of trails and access roads, some of which have been regularly flooded by beavers. Traditionally, management of these areas includes dam removal using explosives, backhoes, and hand tools. Trapping and shooting are used in certain areas. Park staff regularly receive complaints of flooded trails, which often are closed to ensure public safety. Some sites have experienced chronic flooding by beavers for more than a decade, despite ongoing management at these sites. At almost all sites, trails are flooded at least once per year and have resulted in short-term trail closures (up to 2 weeks) or full closure of the trails during the snow-free season.

Human–beaver conflict within the CLBPRA is a microcosm of similar management challenges throughout Alberta. The province has a diverse landscape from high mountains

Figure 2. Study area.

to the west and prairies to the east. The northern extent of the province is dominated by boreal forest. Collectively, there are 64 counties and municipal districts that represent Alberta's rural municipalities. Adverse human–wildlife interactions are managed jointly by the Alberta government and municipal governments, with most issues involving beavers being managed at the municipal level when outside provincial or federal-protected areas. Municipal districts are the most pertinent governance scale for the purposes of this research because they represent governments of rural areas often referred to as "counties" (Alberta Municipal Affairs [AMA], 2016); however, four larger cities and four provincial parks districts also participated. For our study, the combined municipal districts, cities, and park districts are referred to as "municipalities."

Data Collection

Pond-Leveler Installation and Efficacy

Prior to any installations, we used a Garmin 60 CX handheld geographic positioning system to map all sites in the CLBPRA that were actively flooded by beaver activities, all sites that might imminently flood (e.g., water up to trail's edge or on the trail), and any sites that required regular monitoring to update their status. We then mapped these sites using a geographic information system (ArcMap 10.2 by ESRI™, Redlands, California, USA) to create status maps as site classifications changed. Actively flooded sites and those where flooding was imminent were considered "problem sites." Sites were prioritized so the most problematic sites received a pond leveler first.

We incorporated pond-leveler designs (e.g., Callahan, 2003, 2005; Lisle, 2003) and installed 12 pond levelers at problem sites throughout the CLBPRA from 2011 to 2013. Most devices were constructed with one 30-cm diameter 6.1-m-long double-walled high-density polyethylene (HDPE) pipe coupled to a similar 6.1-m-long single-walled HDPE pipe, a 1.22-m-diameter 1-m high circular cage constructed from galvanized hog fencing, and a small protective cage or fence at the end of the outlet of the pond leveler (Figure 1). The submerged end of the double-walled pipe furthest from the beaver dam fit into the circular cage to protect it from beavers, while the single-walled pipe extended through the dam at a height that represents the desired water level in the pond. Once installed, water only flows through the pipe when the pond level rises above the level of the pipe in the dam. For shallower sites, we developed a "mini" pond leveler from 20-cm diameter HDPE pipes. We then regularly monitored the effectiveness of these devices at least biannually and kept detailed records of the time and costs required for monitoring. We determined that a pond leveler was "effective" if water was maintained at the desired level and little to no maintenance was required. Throughout the three years, we documented all construction, installation, and monitoring costs.

Cost–Benefit Analysis

For the cost–benefit analysis within the CLBPRA, we calculated all costs in Canadian dollars (CAD) related to the installation and maintenance for installing pond levelers and custom fencing associated with these devices. To determine typical maintenance costs for the 12 sites prior to the installation of pond levelers, we interviewed park managers (Alberta Parks) with an in-hand survey at the CLBPRA. Questions addressed the annual budget to address beaver management by year, the actual cost (budgeted or not) to address beaver management by year, the number of visitors to the park per year, whether beaver activity resulted in reduced park visitation, and whether installation of a pond leveler resolved issues of reduced park visitation due to beaver activity. We also accessed visitation records from Alberta Parks to determine the number of annual visitors to the park in the nonwinter months (n = 150,000 people) when beavers are most active. For analysis, we assumed that yearly park attendance did not vary. The provincial social discount rate of 3% (SDR – a rate that is used by government-based cost–benefit analyses to compute the amount spent on public projects over time) was used to calculate present value (PV) of benefits and costs of public facilities. An SDR of 7% is currently used for private facilities in Canada and was used in additional analyses.

We used the contingent valuation method to arrive at the "willingness-to-pay" values (WTP) by park visitors. Questionnaires were emailed to the three organizations that consistently use the CLBPRA: Friends of Blackfoot Society, Rainbow Equitation Society, and Alberta Trail Riders Association. To elicit information regarding WTP, the park users were asked to indicate their WTP each time they use the park's fully functioning trail system (e.g., trails free of flooding, damage or closure due to beavers). While flooding on some trails would not necessarily result in park closure, the trails that received a lot of attention for this study were highly popular horse trails and equestrians tend to ride many of the same trails. We also asked participants to indicate their income from which we then constructed seven income groups (earnings under $10,000, $35,000–49,999, $50,000–74,999, $100,000–149,999, and >$150,000) to calculate a weighted-average WTP from which we could determine whether there was an association between WTP and income group (Pearson's correlation, $\alpha = .05$).

Data were acquired by providing payment card values from $0 to $10 in $2 increments, values of $15 and $20, and finally an open-ended choice to indicate a WTP value greater than $20. In general, there are four major elicitation techniques: bidding game (BG), payment card (PC), open-ended (OE), and dichotomous choice (DC). Venkatachalam

(2004) provides the advantages and disadvantages of each technique. We used a combination of payment card and open-ended questions. Champ and Bishop (2006), based on review of several WTP studies, determined that WTP estimates based on DC and PC format tend to be larger than those based on OE method and that the DC estimates seem to be larger than PC estimates. Their study also suggested that PC and OE formats allow for efficient estimation of statistical parameters with smaller sample sizes than the dichotomous choice format. The combination PC and OE in our study allowed users to input any value of their maximum WTP above $20, whereas the payment card approach allowed for users to select from a range of prices (i.e., $0–20).

Unfortunately, these valuation models can contain hypothetical bias and strategic bias, which must be accounted for when examining the data used in the cost–benefit analysis (Venkatachalam, 2004). Hypothetical bias occurs when there is a discrepancy between what users would pay in real life versus what they would pay in a hypothetical situation (Venkatachalam, 2004). This bias can influence users to report WTP at a higher fee under the hypothetical situation (Venkatachalam, 2004). Strategic bias can occur when people understate WTP with the assumption that others would cover the entrance fee (e.g., free-riding, taxation) or overstate WTP with the intention to ensure the "good" would be adequately provided (Oerlemans, Chan, & Volschenk, 2016).

Although there are concerns about range bias using the PC method, Rowe, Schulze, and Breffle (1996) indicated that the range of dollar values was not an issue. We accounted for some of these biases by calculating various scenarios of the cost–benefit analysis using a combination of public and private social discount rates (3% and 7%, respectively) and various levels of WTP. Along with changes in discount rate, WTP values of $0, $2 (the minimum nonzero WTP of survey respondents), and $4 (the median WTP of survey respondents) were used to calculate PV net benefits. These analyses were based on a 3- and 7-year (the expected life span of a pond leveler) time horizon. The costs–benefits related to years 4–7 were based on the average costs–benefits in years 1, 2, and 3. We note that a $0 WTP is equivalent to zero park visitors and the PV net benefit that accrues is because of the intervention. This model served as our "base model."

Model Assumptions

For all cost–benefit analysis (base model and scenarios), we assumed

(1) Data provided by Alberta Parks staff, which outline the costs to manage flooding by beavers using traditional methods for the problem sites, represented the average costs to manage or repair all problem sites if water levels were to get too high once a year.
(2) Monitoring costs for the 12 sites where installations occurred were considered to be the same across all sites, regardless of location or site-specific considerations.
For the seven models that included some estimate of WTP or variable discount rates, we also assumed
(3) The number of park users in the nonwinter months (150,000 people) was constant for all 2011–2013. Alberta Parks provided traffic count data from November 2011 to April 2013. We used the traffic count data from April to September 2012 (nonwinter months when beavers are active) and information (personal communication) provided by park staff to estimate the number of park users per summer.

(4) Data collected from park users represented the population of all users attending the park.
(5) The weighted-average WTP represented the entire population. We assumed that park users who responded to the survey were broadly reflective of the average park visitor. Thus, the weighted-average WTP represents the entire population. To derive the weighted WTP, we generated an average-weighted WTP (AWTP) for different income groups. We then calculated the sum of AWTP and multiplied it by the number of observations in each income group. Finally, we obtained the weighted WTP by calculating the sum of AWTP and then dividing it by the number of observations.

Model Inputs

The cost–benefit analysis was based on conversion of current value (CV) pond-leveler expenses, monitoring costs, and mitigated expense benefits to PVs based on the formula $PV = CV(1+SDR)^{year}$, where SDR is the social discount rate, and the exponent "year" allows for a time series of CVs for the study period. Data collection of individual values included the following items for costs: (a) install expenses: supplies and equipment, material and site preparation, labor and transportation; and (b) monitoring and maintenance costs: supplies and equipment, labor, and transportation. We incorporated any maintenance costs required by all pond levelers over the course of the study into our analysis.

Benefits included Alberta Parks mitigated repair expenses based on the 2011–2013 annual expenses averaged for all 12 sites, including labor and equipment costs, and WTP average-weighted benefit (derived from weighted WTP multiplied by the estimated users per year). We assumed that every visitor coming to the CLBPRA pursued a trail-related recreational activity, the utility of which would be diminished if they encounter a flooded trail. This assumption was supported by the park's primary focus being its extensive trail system. The trails were supplemented with limited front country facilities (e.g., outhouses, picnic shelters).

We applied these costs to the analysis with the assumption that each site would only require maintenance or repair by park staff once per year. However, in our discussions with park staff and personal observations, it became obvious that most of our sites required multiple maintenance visits by parks staff prior to installation of pond levelers. Given the lack of record-keeping by staff that would allow us to fully quantify these visits, our quantification of these expenses was conservative. Mitigated repair expenses were those expenses that would be incurred by the park, if pond levelers were not installed. Park expenses did not include regular trail maintenance costs unrelated to flooding by beavers (e.g., clearing brush).

Analysis

We inputted all financial data into a spreadsheet to facilitate the comparison of monetary capital costs to build and maintain pond levelers (operating costs) to the benefits (both monetary and nonmonetary) of installation and mitigation of beaver-impacted facilities. The main variables for the cost–benefit analysis included the PV of pond-leveler expense, PV monitoring costs, PV cumulative benefits, and the net present value (NPV) computed as PV of benefits minus PV of costs.

Province-Wide Municipal Management Approaches and Expenses

To quantify province-wide costs for beaver management beyond the area where we installed pond levelers (CLBPRA), we contacted all regional municipalities in the province and four Alberta Parks districts ("municipalities") by phone to determine whether they agreed to participate in surveys. If they agreed, we emailed the survey to government staff who then received a mail-in questionnaire (including electronic mail). The survey included questions on methods used to address beaver management in their jurisdiction, annual budgeted costs for beaver control, maintenance at beaver–conflict sites, repairs at beaver–conflict sites, and actual incurred costs for each cost category. For management methods, we summarized the number of beaver management methods used by municipalities and the proportion of methods used by municipalities. From the surveys, we calculated summary statistics for (a) budgeted costs for beaver control, (b) budgeted costs for maintenance at beaver–conflict sites, (c) budgeted costs for repairing damage at conflict sites, and (d) actual costs for each of those budgeted costs. Finally, we determined the difference between budgeted costs and actual expenditures, as well as province-wide annual expenditures for beaver management.

Results

Pond-Leveler Installation and Efficacy

From 2011 to 2013, we installed 12 pond levelers in the CLBPRA, with installation expenses ranging from $319 to $1,635 per site (CAD). The variation in expenses primarily reflected the installation of a smaller version of a pond leveler at one site, to ongoing issues with one site that required repeated attention until it was resolved. The average cost for installing a pond leveler was $899 and a total cost of $10,792 over 3 years, excluding monitoring and start-up costs (Tables 1 and 2). Additionally, monitoring all 12 sites for a year was estimated to cost $128 per site. Monitoring costs include labor and transportation.

Over 3 years, only one site required ongoing repair and maintenance until we designed a "mini" pond leveler with 20-cm diameter HDPE pipes and a shorter cage. The shallower nature of the site and presence of a culvert made the standard installation difficult. Since the installation of the "mini" in 2013, the site has not required any maintenance. The initial two pond levelers installed on the Blackfoot trail in 2011 have functioned well since their installation and have required no maintenance. This section of the trail, which had been closed on and off for the past 10 years because of flooding by beavers, has continued to remain dry for 7 years (including 2017). Two sites installed in 2012 and six installed in 2013 are still in good working order. One additional pond leveler installed in 2013 required some minor maintenance to extend the 20-cm pipe along a narrow stream bed to prevent beavers from damming below the end of the pipe. The pond leveler was working, but the beavers moved their damming activities below the pond leveler, thus creating a secondary impoundment. We extended the pipe in 2014, and it has continued to mitigate the problem 3 years later.

Cost–Benefit Analysis

We compared traditional and alternative management costs from 2011 to 2013 (Table 1) and ran a "base model" cost–benefit analysis that excluded WTP values (Table 2). To assess other scenarios, we ran various cost–benefit analyses with adjusted WTP values ($2,

Table 1. Costs for installing and monitoring 12 pond levelers, and the estimated costs for traditional management at the sites in the Cooking Lake/Blackfoot Provincial Recreation Area in Alberta, Canada, from 2011 to 2013.

Costs of installation of pond levelers/management	2011	2012	2013	Total
Number of pond levelers	3	1	8	12
Start-up materials	$1,672	$0	$0	$1,672
Pond-leveler installations	$2447	$877	$7,468	$10,792
Average monitoring and mapping	$1,540	$1,540	$1,540	$4,620
Cumulative costs for pond levelers	$5,659	$2,346	$8,491	$16,496
Average annual park management expenses	$33,642	$33,642	$33,642	$100,926

The number of pond levelers installed per year varied due to project funding and logistics; however, all 12 sites were problematic in 2011 until pond-leveler installations began. Average cost for monitoring of the pond levelers was $128 per site. For years prior to installation, those costs apply to the mapping and assessment of the sites. Park management expenses were obtained through a questionnaire and in-person interviews, then averaged over the 3 years (an average of $2,803 for each of the 12 sites). The park management costs represent the costs the park would have incurred if pond levelers were not installed. All costs in CAD.

Table 2. Base-case scenario and various sensitivity analyses representing cost–benefit analysis of traditional and alternative management of flooding by beavers at 12 sites in the Cooking Lake/Blackfoot Provincial Recreation Area, Alberta, Canada.

Year	NPV (DR 3%, WTP $0) (base case)	NPV (DR 3%, WTP based on minimum nonzero value $2) (I)	NPV (DR 3%, WTP based on median value $4) (II)	NPV (DR 3%, WTP $6.00) (III)
2011	$27,983	$327,983	$627,983	$927,983
2012	$30,316	$321,578	$612,840	$904,102
2013	$23,220	$305,999	$588,778	$871,556
Total	$81,519	$955,560	$1,829,601	$2,703,642
		Cumulative NPV to year 2017 (# of years = 7)		
	$179,440	$2,104,597	$4,029,754	$5,954,912
Year	NPV (DR 7%, WTP $0) (IV)	NPV (DR 7%, WTP based on minimum non-zero value $2) (V)	NPV (DR 7%, WTP based on median value $4) (VI)	NPV (DR 7%, WTP $6.00) (VII)
2011	$27,983	$327,983	$627,983	$927,983
2012	$29,183	$309,557	$589,930	$870,304
2013	$21,516	$283,548	$545,580	$807,611
Total	$78,682	$921,088	$1,763,493	$2,605,899
		Cumulative NPV to year 2017 (# of years = 7)		
	$161,366	$1,891,327	$3,621,289	$5,351,251

Pond levelers were installed at these sites from 2011 to 2013. Analyses were extended to 7 years – the documented current effectiveness of pond levelers. Present value (PV) cumulative costs include installation costs for pond levelers and annual cost to monitor all 12 sites ($128 per site). PV cumulative benefits include mitigated repair expenses (expenses incurred by Alberta Parks if there were no pond levelers at the sites). Scenarios I to VII include varying willingness-to-pay (WTP) values and either a 3% public social discount rate or a 7% private discount rate (DR). The net present values (NPV = PV benefit–PV cost) in Canadian dollars are reported below.

$4, and $6) that reflected common park users fees (e.g., Parks Canada daily entrance and facility rates) and discount rates to provide PV net benefits based on all park users in the nonwinter months (150,000 people).

Due to inconsistent funding and staffing (Table 1), annual costs for pond-leveler installations and monitoring were variable. Park managers reported that installation of pond levelers mitigated trail repair expenses of $2,803 per site per year on average. Much of the savings was due to mitigated maintenance costs at two popular trails, JJ and

Blackfoot. Although we observed park staff returning to problem sites at least weekly, this level of maintenance data was unavailable. We assumed each site experienced flooding only once per year.

The base model that excluded estimated WTP from the analysis (WTP = \$0) produced a PV net benefit of \$81,519 for the 12 sites over 3 years and \$179,440 over a 7-year period (the currently documented life span of pond levelers; Table 2). With the installation of pond levelers, these values reflect a \$19,401 savings for the park over 3 years and a savings of \$56,054 projected over 7 years. Our analyses based on variable discount rates (i.e., 3% or 7%) and WTP scenarios (\$2, \$4, \$6.00) resulted in PV net benefits ranging from \$78,682 to \$2,703,642 over 3 years and from \$161,366 to \$5,954,912 over 7 years.

Province-Wide Municipal Management Approaches and Expenses

Of the 64 municipalities and parks districts we contacted in Alberta, 52 (81%) responded to our survey (Figure 2). On average, municipalities used just over two different methods for managing beaver problems. However, some used as many as seven different methods for managing beavers, including trapping, shooting, dam removal, and poisoning (Figure 3). Of the 52 municipalities, 10 relied solely on lethal means for controlling beavers. Despite using the same control methods, municipal budgets were dramatically different. Within these methods, three municipalities used pond levelers once or twice and only two counties use public education to help mitigate conflicts. Of all methods, removing dams with explosives or backhoes and trapping or shooting beavers were most common. Although three municipalities said they had used a flow device, this use was rare even within these jurisdictions.

Mean budgeted costs indicated in the survey were approximately the same as the actual costs; with an average annual cost for beaver control of \$21,933, maintenance of \$22,115, and repair of \$86,500 annually (Table 3). However, managers indicated that costs would vary depending on drought conditions; for example, in dry years, conflicts with beavers

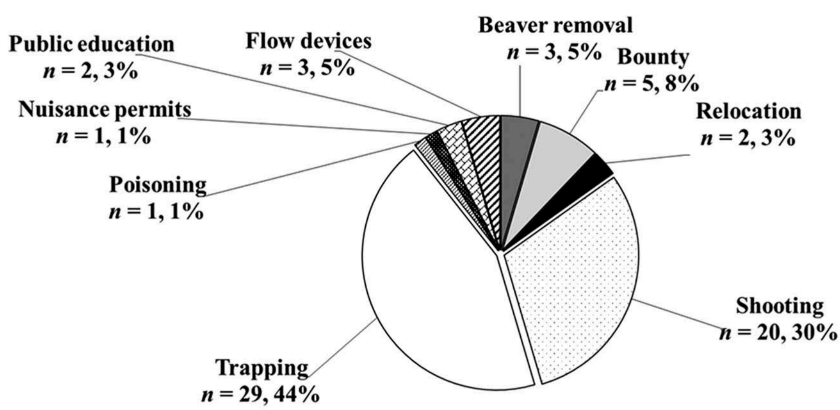

Figure 3. Methods used by 48 Alberta municipalities and four Alberta Parks districts for beaver management. Numbers indicate the number of jurisdictions using the method, while percentages indicate the percentage of jurisdictions using the method. Jurisdictions often employed more than one method to manage conflicts with beavers.

Table 3. Responses for budgeted and annual costs (CAD) for control, maintenance and repair at beaver–conflict sites for Alberta municipalities (*n* = 52 respondents) in 2013.

Annual budget items or actual costs	Median (IQR)	Mean (SD)	Maximum	Minimum (min > $0)	Number of respondents
Beaver control Q4	$3,000 ($20,100)	$26,675 ($62,440)	$375,000	$0 ($500)	52
Maintenance at beaver conflict sites Q5	$2,250 ($20,000)	$24,963 ($62,721)	$375,000	$0 ($2,000)	51
Repair at beaver conflict sites Q6	$0 ($15,000)	$19,767 ($41,982)	$150,000	$0 ($500)	48
Actual annual cost for beaver control activities Q7	$2,950 ($17,700)	$21,933 ($42,413)	$154,875	$0 ($100)	49
Actual annual cost for maintenance of beaver conflict sites Q8	$5,000 ($27,225)	$22,115 ($33,888)	$150,000	$0 ($200)	47
Actual annual cost for repair at beaver conflict sites Q9	$2,000 ($20,000)	$27,705 ($48,292)	$200,000	$0 ($100)	37

When exact costs were not provided, maximum budgeted costs for that jurisdiction were used. The statements before the questions indicate the nature of the question asked of the municipalities (e.g., Q5 "What were the annual budget items or actual costs for maintenance at beaver conflict sites?").

were less likely and thus likely to be less costly to manage than relatively wetter years. For maintenance, there was a larger discrepancy. The highest annual cost budgeted for beaver control was $375,000 in Smoky Lake County. Dry prairie regions and some boreal municipalities (*n* = 21) had no budget for beaver control or management, although 10 of these jurisdictions had actual incurred costs for beaver management.

Costs for repair of damage from beaver activities were often higher than budgeted amounts, with a maximum annual cost for repairs at beaver conflict sites reaching $200,000. Repair costs exceeded budgeted amounts for 74% of the municipalities where beaver–conflicts occurred. Additionally, costs for beaver control exceeded budgeted amounts in 52% of the municipalities, and costs for maintenance were exceeded in 67% of municipalities, where beavers occurred. Of the 52 municipalities that responded to our survey, budgeted costs matched exactly what was reported for beaver control in 49% of the jurisdictions, 43% for maintenance at beaver–conflict sites, and 49% where sites required repair. At times, there were a number of "no data" responses for either budgeted or actual costs, which indicated incomplete accounting measures within the municipalities. Total actual cost per year for beaver management for the 52 municipalities combined was $3,139,223. All values were in Canadian dollars.

Discussion

Management of human–wildlife conflicts has often relied on lethal control and removal of wildlife-created structures (e.g., dams, nests, burrows) (Bergstrom et al., 2014; Taylor & Singleton, 2014). As DeStefano and Deblinger (2005) noted, perception of a species as an important resource or unwelcome pest can change relative to species abundance, the form of human–wildlife interaction and personal experience with the species in general. With beaver control, we confirmed that ponds and wetlands are drained regularly, regardless of their ecological importance or the time of year (Hood & Larson, 2014; Law et al., 2016; Wright et al., 2002). Increasingly, nonlethal management is proving an effective and financially prudent means to address both the structural and ecological assets in areas where conflicts exist (Boyles & Savitzky, 2008; Taylor & Singleton, 2014). Growing support for adaptive wildlife management approaches (DeStefano & Deblinger, 2005) provides an opportunity for new tools in the management and assessment of human–wildlife interactions. Through the installation of pond levelers at 12 chronically flooded areas and a multiyear cost–benefit analysis, our research indicates that economic advantages for using nonlethal methods of beaver control could be significant at various levels of government.

As observed at sites chronically flooded by beavers, pond levelers provide a cost-effective alternative to traditional management approaches (e.g., dam, colony removals). At a PV net benefit of $81,500 for 12 sites over 3 years and $179,440 over 7 years (WTP = $0), our study confirmed similar findings by Boyles and Savitzky (2008). Their research in the Coastal Plain of Virginia determined that the Virginia Department of Transportation saved $372,508 for 14 study sites where they installed flow devices similar to the pond levelers we installed in east-central Alberta. Although the methodologies and time scales vary, our studies demonstrate distinct financial and maintenance benefits with the installation of flow devices.

In addition, difficult fence and commercial device installation required a pipe system extending through the culvert or dam at chronically flooded areas. Due to these challenges, repairs at the sites prior to installing additional pipes required repeated visits, which increased overall costs. Once our experience and expertise increased, we were able to install a pond leveler in less than an hour, depending on site access and preparation of cages and pipes in advance.

Various scenarios incorporating differing WTP values and discount rates realized even greater benefits than those described above with a range of cumulative net benefits of $1,891,327–5,954,912 over 7 years. Given the location of the park and its proximity to Edmonton, with a metropolitan population of about 1 million, and a population growth of 3.7% per year between 2012 and 2014, a constant number of 150,000 parks users is a conservative estimate.

Increasingly, flow devices (e.g., Flexible Pond Leveler™, Callahan, 2003; 2005; Beaver Deceivers™, Castor Masters™, Lisle, 2003) are being used by various governmental and nongovernmental organizations (Boyles & Savitzky, 2008; Simon, 2006) as alternatives to traditional management techniques (e.g., dam removal, colony removal). Formal cost–benefit analyses, however, are less common, especially over multiple years. Boyles and Savitzky (2008) provide a compelling cost-accounting and analysis of the efficacy of specific flow devices used in the eastern U.S.. Our research, although different in design, complements their study and extends it to a rare province-wide cost-accounting.

As seen here, obtaining clear cost-accounting from municipalities through semistructured interviews was difficult. For those municipalities where there was no difference from what had been budgeted for beaver management and actual expenditures, some were dryland municipalities that lacked waterbodies that could support widespread beaver populations. For those municipalities with beavers and perfectly balanced budgets, such accounting might be encouraged by internal economic policies enforcing balanced budgets rather than operational realities (Lowry, 2001). To obtain an exact value for municipal expenditures, we would need to examine the accounts themselves rather that work with semistructured surveys.

With increasing ecological challenges, such as wetland loss (Bedford, 1999; Junk et al., 2013) and global warming (Schindler & Donahue, 2006), environmentally and economically appropriate approaches to human–wildlife interactions can help balance financial challenges with demands from the public for adaptive wildlife management. In addition to the ecological challenges, with municipalities facing budgetary pressures an efficient way to address human–wildlife conflict (especially in the context of beaver management) is important. We have, in our article, attempted to address these issues. Although not a new tool, cost–benefit analysis combined with on-the-ground testing of alternative approaches can inform more effective management of our natural resources.

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Mitigating infrastructure loss from beaver flooding: A cost–benefit analysis

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