ENUMERATION OF POTENTIAL ECONOMIC COSTS OF DREISSENID MUSSELS INFESTATION IN MONTANA

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Table of Contents

List of Figures

List of Tables

Executive Summary

Introduction

In fall 2016, dreissenid or invasive mussel larvae were detected in Tiber Reservoir with a suspect detection in Canyon Ferry Reservoir. Invasive mussels are referred to as ecosystem engineers because of their profound effects on lake and river ecosystem function and structure. Since their discovery in the Great Lakes in the late 1980s dreissenid mussels have caused substantial economic impacts.

With the imminent threat of additional dreissenid mussel introduction, managers and policy makers in Montana need cost estimates to inform decisions about the appropriate level of investment in prevention programs and efforts at containing existing detections. The objective of this research was to provide estimates of the potential economic damages due to dreissenid mussels.

Approach

- Identified affected stakeholders and their respective usage of the resource, whether consumptive or non-consumptive.
- Consumptive use estimates of economic damages were based on reported expenditures from facilities in locations with dreissenid mussels. Costs were converted to a per volume of water treated basis.
- Non-consumptive use estimates of economic damages were based on percent reductions in either participation rates or value, or a per unit mitigation costs.

Assumptions

- Dreissenid mussels were assumed to colonize all water bodies across Montana at their maximum potential. In other words, the probability of introduction, establishment, dispersion, and abundance were not taken into account.
- Cost estimates were based on damages that would result from established dreissenid mussel populations at infestation levels similar to conditions in the Great Lakes.

Results

The potential economic damages if dreissenid mussels were to colonize all water bodies in Montana totaled $72.4 to $121.9 million in mitigation costs, $23.9 to $112.1 million in lost revenue, and $288.5 to $497.4 million in property value losses (Table 1). Not including property value losses, the top three stakeholder groups facing the largest potential economic impacts from dreissenid mussel invasion were tourism, hydropower, and irrigation accounting for 60 to 75 percent of the total potential damages statewide.

The potential economic damages summarized below should be interpreted with the following information in mind. The economic impacts of dreissenid mussels were available for certain stakeholder groups while lacking for others. Mitigation costs were based on direct expenditures from facilities with dreissenid mussel infestation; thus, the mitigation cost estimates presented herein are for specific mitigation options. The actual cost of mitigation will depend on facility size and complexity, operating conditions, and choice of mitigation strategy. Dreissenid mussel impacts to tourism, recreational fishing, and property values have yet to be explicitly quantified; therefore, cost estimates for these stakeholders were based on percent reductions in participation or using similar studies as proxies for mussel-related impacts.

Importantly, this analysis underestimates the total impacts of dreissenid mussels to society. Values not accounted for include the disruption of ecosystem functions and their attendant services that support human economic activity, as well as the benefits people derive from knowing a lake or river exists without actually using the resource.

Table 1. Summary of Potential Damage Costs for Dreissenid Mussels Statewide

	Montana	
Stakeholder Group	Lower Bound	Upper Bound
Annual Costs		
Mitigation Costs		
Irrigation	$29,250,000	$60,499,000
Hydropower	$10,431,000	$25,325,000
Recreational Boating	$13,951,000	$13,951,000
Thermoelectric Power	$7,930,000	$8,272,000
Public Supply	$7,397,000	$7,716,000
Self-Supply Domestic	$550,000	$3,004,000
Mining	$2,170,000	$2,264,000
Industrial	$476,000	$497,000
Livestock	$93,000	$193,000
Aquaculture	$159,000	$166,000
Mitigation Cost Total	**$72,407,000**	**$121,887,000**
Lost Revenue		
Tourism	$17,800,000	$89,001,000
Recreational Fishing	$3,867,000	$19,337,000
Property Tax Revenue	$2,190,000	$3,776,000
Lost Revenue Total	**$23,857,000**	**$112,114,000**
Total Mitigation + Lost Revenue	**$96,264,000**	**$234,001,000**
One-Time Investment Loss		
Private Property [1]		
Property Value Loss Total	**$288,498,000**	**$497,410,000**

[1] Does not include the potential loss in value to irrigated farmland.

Discussion

The current level of Montana's AIS funding, approximately $6.5 million, is roughly 7 percent of the lower bound estimate of $96.3 million, the sum of potential mitigation costs and lost revenue. Prevention and early detection and rapid response are considered the most cost-efficient approaches to minimizing the economic damages of dreissenid mussels and other aquatic invasive species. Once established, adult dreissenid mussels can not be eradicated leaving damage mitigation and control as the only feasible and more costly policy responses.

1. Introduction

Invasive species cause substantial ecological and economic damage. Whereas intentional species introduction has been helpful to many sectors of the U.S. economy, some nonindigenous species have likely caused up to $120 billion per year in environmental damage and control costs (Pimentel, Zuniga, & Morrison, 2005). National level estimates of the economic costs of invasive species are useful for drawing attention to a real threat posed by these unintentional introductions and spurring federal policy makers in to action. The creation of the interagency Invasive Species Council in February 1999 by Executive Order is one example of federal action to address the introduction of nonnative species that become invasive (Pimentel et al., 2005). However, these national level estimates are highly aggregated curtailing their use at more localized levels or for partitioning the impacts among affected users. The lack of scalability and identification of affected stakeholders minimizes the usefulness of the estimates to managers working at the regional, state, or local level.

At the same time, state and regional managers increasingly rely on studies that evaluate the economic impact of invasive species in their particular locality to justify needed funds for prevention, containment, and eradication programs (Cusack, Harte, & Chan, 2009). The difficulty with producing timely cost estimates that are useful to these managers stems from the lack of systematic accounting of damages and control costs caused by invasive species. In 1993, the U.S. Office of Technology Assessment reported on the "chronically underestimated" numbers and impacts of invasive species. Without systematic documentation estimates of economic impacts are incomplete and undervalued (U.S. Congress, 1993). The absence of precise economic accounting of even the most ecologically damaging invasive species continues to be a problem (Lovell, Stone, & Fernandez, 2006; U.S. Department of the Interior, 2016). Reliable and consistent measures of invasive species impacts are needed to better understand their effects on the U.S. economy. More importantly, standardized data collection and analysis will allow for comparability across studies increasing their value and usability among those making policy decisions (Cusack et al., 2009).

One such invasive species that has caused substantial economic impacts is the zebra mussel (*Dreissena polymorpha*). The economic damages from zebra mussels on drinking water and electric power generation facilities was estimated at $267 million between 1989 and 2004 (Connelly, O'Neill, Knuth, & Brown, 2007). Pimentel and others (2005) estimated zebra and the related quagga mussel (*D. rostriformis bugensis*), hereafter collectively referred to as dreissenid mussels, caused $1 billion in damages and control costs annually. Dreissenids are invasive freshwater mussels that were discovered in the Great Lakes in the late 1980s (Kelly, Lamberti, & MacIssac, 2009). Dreissenid mussels have since spread widely across North America with 32 states reporting positive detections (Benson, Raikow, Larson, Fusaro, & Bogdanoff, 2018).

The ecological effects of dreissenid mussels are considered the most far-reaching relative to other aquatic invasive species (AIS), causing local extinction of many native mollusks, changing the structure of food webs and fish assemblages, and contributing to the collapse of valuable sport fish populations (Kelly et al., 2009; Bossenbroek, Finnoff, Shogren, & Warziniack, 2009; Strayer, 2009; Pimentel et al., 2005). Once established, these mussels commonly reach densities in excess of 100,000 individuals/ft^2 (Higgins & Vander Zanden, 2010) clogging pipelines and water intakes and disrupting operations at hydroelectric power plants, municipal water supply facilities, conveyance systems used in irrigation, among others. Boaters too will face increased costs from mussels growing on hulls, engines, and steering components. Beaches can become unusable due to the sharp shells and pungent odors of dead mussels washing ashore. A consequence of biofouling organisms like dreissenid mussels is that the costs to mitigate are shared among the populace.

The need for up-to-date cost estimates of dreissenid mussel impacts at a scale that is useful for managers and decision-makers at the local, state or regional level led to the development of an approach to estimating costs that is scalable, general, and predictive. To demonstrate this approach this study uses Montana as a case study. Montana contains headwater streams for the Columbia and Missouri River Basins (Figure 1). In fall 2016, quagga mussel larvae (veligers) were detected in Tiber Reservoir with a suspect detection in Canyon Ferry Reservoir. These reservoirs are east of the Continental Divide and are part of the Missouri River Basin. Thus, the Columbia River Basin is the last major river basin in the continental United States that is known to be mussel-free at this time. Given adult dreissenid mussels have yet to be established in Montana, the approach used here in estimating damages is an extrapolation of the mussel mitigation and damage costs borne by others elsewhere.

With the imminent threat of additional spread of dreissenid mussels, managers and policy makers in Montana are in need of cost information that will inform the appropriate level of investment in prevention programs and efforts at containing existing detections. The objective of this research was to provide estimates of the potential economic damages due to dreissenid mussels for the state as a whole and to scale the results to the two major river basins. To meet this objective I identified affected stakeholders and their respective usage of the resource calculating estimates of the potential economic damages for each stakeholder group should dreissenid mussels successfully invade the state's waters. Estimating costs of dreissenid mussels as a function of per facility costs is common practice (U.S. Army Corps of Engineers [USACE], 2009; Marbek, 2010; Idaho Aquatic Nuisance Species Taskforce, 2009); however, here I will translate cost estimates to a per volume basis thereby standardizing damages for application at differing scales and locations.

2. Study Design

This study quantifies the magnitude of the potential economic damages due to dreissenid mussels should they invade and thrive in Montana's rivers, lakes, and reservoirs. My approach was to identify the scope of affected uses of surface waters, quantify the amount of use, and multiply by the cost. The sections following address each of these components of the study.

Economic damage estimates derived in this study were based on either 1) direct expenditures from facilities in locations infested with dreissenid mussels or 2) scenarios depicting percent reductions in either participation rates or value due to the presence of dreissenid mussels. The damage cost method, as this approach is known, measures the damage "costs avoided" due to prevention efforts and represent a lower bound estimate of the benefit of protecting Montana's surface waters from invasion by dreissenid mussels (Young & Loomis, 2014). The general premise of using the cost brought on by invasive mussels is that the affected individual or household is willing to pay up to the amount of expected damages to avoid them (Young & Loomis, 2014). Hence, the cost of damages can be used as a measure of the benefit of proposed policies to prevent or mitigate potential damages.

The expected value of economic damage arising from dreissenid mussels is a function of their introduction, establishment, dispersion, and abundance. In this analysis I assume that dreissenid mussels would grow and reproduce at their maximum potential across all waters of Montana, ignoring the probabilities of introduction and successful establishment of mussel populations after introduction. Thus, the estimates presented in this study are the cost of damages that would result from established dreissenid mussel populations throughout every water body in the state of Montana at infestation levels similar to conditions in the Great Lakes, for example.

All cost estimates are new enough to be presented in nominal dollars, which are dollars that measure prices that have not been adjusted for the effects of inflation. In other words, nominal dollars reflect the prices paid for products or services at the time of the transaction.

3. Surface-Water Use Categories and Usage

Unlike previous studies that derive costs per facility, I based my economic damage estimates, in part, on the quantities of water withdrawn by category of use. I adopted this approach for two reasons. First, the water withdrawal data are readily available for all states by county and are updated every five years. Second, the data are comprehensive, simplifying the task of accounting for each stakeholder group in its entirety. Accordingly this approach distinguishes between consumptive and nonconsumptive uses of water. Water that is withdrawn from a river or lake or reservoir for a particular use, and thus not readily available for other uses, is a consumptive use. The U.S. Geological Survey (USGS) compiles water withdrawal estimates for the U.S. and individual states every five years. Withdrawals are reported by category of use: public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power. I used estimates of Montana's average daily water withdrawal from the 2015 USGS compilation report (Dieter et al., 2018) to calculate potential economic damages from mussel infestation for all eight categories (Table 1).

Water also derives value without leaving the hydrologic system; these in place uses result in little or no physical loss and are typically called non-consumptive uses. Estimates of economic damages were based on the potential reduction in use or value of the resource from mussel-induced degradation. The economic impacts quantified in this manner were completed for recreational fishing, tourism, property values, and property tax revenue . An additional non-consumptive use category, hydroelectric power generation, was also included in the analysis with the potential economic impact being estimated on a per generator basis and from reductions in electricity generation.

Table 1. Total Average Daily Surface Water Withdrawals

	Withdrawal (Mgal/d)		
Category	Statewide	Columbia River Basin	Missouri River Basin
Irrigation	9,393	1,233	8,160
Thermoelectric	74.9	--	74.9
Public Supply	69.9	12.0	57.9
Livestock	29.9	2.2	27.7
Mining	20.5	9.0	11.5
Aquaculture	13.6	4.9	8.7
Industrial	4.5	0.5	4.0
Domestic Self-Supply	1.1	1.0	0.1

Note: Mgal/d, million gallons per day

4. Mitigation Options

Many mitigation methods and strategies are available for minimizing the impacts of dreissenid mussels. Due to physical, environmental and regulatory factors, no single method or strategy is appropriate for all situations. Furthermore, individual state agencies, tribes, industries, and municipalities may choose to employ different control methods depending on their situation and regulatory structure. Below is a brief summary of the more common control methods in use today. For an in-depth review of methods and strategies see documents prepared by the USACE (2013) and the U.S. Bureau of Reclamation (Reclamation; 2015).

The options for mitigating dreissenid mussels impacts include both chemical and physical methods. Many of these options are suitable across industries, from water treatment plants to hydroelectric facilities to irrigation systems. Physical control measures can include scraping, power washing, filtration, thermal treatment, ultra-violet light, desiccation, and oxygen deprivation (USACE, 2013; Chakraborti, Madon, & Kaur, 2016). In addition, coatings containing copper, brass, and zinc repel mussels preventing their growth on infrastructure surfaces (USACE, 2013). Also available are environmentally-friendly coatings that lack biocides, known as foul-release coatings, which are highly effective against mussel fouling; however, foul-release coatings are susceptible to abrasion and gouging (Wells & Sytsma, 2013). Chemical treatments might include chlorine, potassium permanganate ($KMnO_4$), pH adjustment, copper-based aquatic herbicides, potash, and proprietary molluscicides (e.g., Zequanox), among others. The advantages of chemical control are convenience, cost-effectiveness, and whole facility protection. However, the downside is limiting the discharge of chemicals to receiving waters, which can harm aquatic ecosystems and may need special permitting to meet environmental regulations. For instance, a major concern with using chlorine is the formation of disinfection byproducts including trihalomethanes (THMs) and haloacetic acids. THMs are regulated by the Environmental Protection Agency (EPA), which may limit the use of chlorine in plants that are at or near the EPA limit (USACE, 2013; Chakraborti et al., 2016).

5. Results – Cost Calculations

5.1 Irrigation & Livestock

Regardless of the irrigation system used, all irrigators will need to manage for mussel larvae (veligers) colonizing within irrigation infrastructure. Dreissenid mussels will impact pumps, pipelines, sprinklers and emitters, gated pipe and siphon tubes, and stock watering systems (L. Pennington, personal communication, June 27, 2018). For instance, veligers drawn into pumps can settle out to interfere with the pumps operation, increasing wear on the pump impeller and prompting additional maintenance. Similar impacts are expected for ranchers relying on surface water withdrawals for livestock. However, few studies or cost data exist documenting the economic impacts of dreissenid mussels on irrigation systems because the extent of mussel infestation to date has been in agricultural regions with sufficient rainfall to support crops.

In 2015, surface water withdrawals for irrigation totaled 9,393 million gallons per day (Mgal/d) or 10.5 million acre-feet per year (acre-ft/yr; Dieter et al., 2018). The irrigation water withdrawal estimate includes irrigation of crops, golf courses, parks, nurseries, turf farms, and cemeteries as well as conveyance losses. Livestock water withdrawal equaled nearly 30 Mgal/d or 10.9 billion gallons per year and includes water used for livestock watering, feedlots, dairy operations, and other on-farm needs. To estimate the cost to irrigators and ranchers in Montana, I used rate data from the Coachella Valley Water District, an irrigation water supplier in southern California that assesses a quagga mussel mitigation surcharge. The current mitigation surcharge is $2.78 per acre-foot but has been as high as $5.75 per acre-foot. The current and past surcharge rates were used to calculate lower and upper bound estimates of the potential cost to irrigators and ranchers in Montana from dreissenid mussel infestation (Tables 2 and 3).

The Coachella Valley Water District adds liquid chlorine into their canals a few miles from where the waterway begins to prevent quagga mussels from colonizing their infrastructure. Despite the differences in water conveyance systems between southern California and Montana, the rate charged by Coachella Valley Water District reflects the actual cost of using chemical control to mitigate against quagga mussel impacts. Furthermore, the management of dreissenid mussels at the point of diversion is the most suitable and likely approach to be adopted by Montana irrigators and ranchers. Other chemical controls are available to prevent dreissenid mussel colonization of irrigation infrastructure including copper-based aquatic herbicides (e.g., Natrix™), potash, and proprietary molluscicides (e.g., Zequanox™). Pilot studies testing the efficacy of these chemical treatments, however, generally found higher costs per volume of water treated than chlorine.

Two caveats regarding the potential cost to irrigators from dreissenid mussel infestation are worth further discussion. First, some fraction of Montana irrigators continue to use flood irrigation methods that rely on siphons. Irrigators with this type of system will likely use manual means – scraping, desiccation – to control mussel growth. As such, these irrigators would incur lower costs than the cost of chemical treatment. However, the proportion of irrigation water withdrawals used in these systems is unknown and thus were not separately quantified. Second, the potential costs to irrigators presented here do not include the potential impacts to property values. The value of agricultural land, in theory, should be a determined solely by the expected net earnings arising from the agricultural production of the land. Conceivably, the additional cost to irrigate would reduce the price a farmer might negotiate for their arable farmland because of lower expected net earnings. Estimation of this mussel-induced impact was beyond the scope of this study.

Table 2. Potential Annual Mitigation Costs to Farmers using Sprinkler Irrigation Systems

	Annual Withdrawals (thousand acre-ft/yr) (a)	Mussel Mitigation Rate (per acre-ft) (b)	Potential Costs (a × b)
Lower Bound Estimate			
Montana	10,520	$2.78	$29,250,000
Columbia River Basin	1,380		$3,840,000
Missouri River Basin	9,140		$25,410,000
Upper Bound Estimate			
Montana	10,520	$5.75	$60,499,000
Columbia River Basin	1,380		$7,942,000
Missouri River Basin	9,140		$52,557,000

Table 3. Potential Annual Mitigation Costs to Ranchers

	Annual Withdrawals (Mgal) (a)	Mussel Mitigation Rate (b)	Costs (a × b)
Lower Bound Estimate			
Montana	10,914	$8.53	$93,000
Columbia River Basin	803		$7,000
Missouri River Basin	10,111		$86,000
Upper Bound Estimate			
Montana	10,914	$17.65	$193,000
Columbia River Basin	803		$14,000
Missouri River Basin	10,111		$178,000

5.2 Water Treatment Facilities (Public Supply)

Public water supply in Montana is comprised of 45 facilities (Dutton, personal communication, August 7, 2018). Public water supply systems, otherwise known as the city or county water department or water treatment plant, are publicly or privately owned facilities that withdraw water from rivers, lakes, or reservoirs and then deliver the treated water for domestic, commercial, and industrial purposes. In 2015, surface water withdrawals for public supply served 39 percent of Montana's population (Dieter et al., 2018). The variation in the capacity to treat surface water among Montana's facilities is illustrated by the average daily surface water withdrawals, which range from 0.02 Mgal/d to 21.7 Mgal/d (Dutton, personal communication, August 7, 2018). Two thirds of Montana's water supply systems are small, less than 1 Mgal/d.

Dreissenid mussels can colonize nearly any surface where flows are less than 6.5 feet per second (O'Neill, 1993). Once attached, biofouling can clog intake pipes restricting flow and impeding operations (Chakraborti et al., 2016). Water treatment plant infrastructure at risk from dreissenid mussel infestation includes intake structures, screens, pumps, small diameter piping and valves, and instrumentation, among others (Chakraborti et al., 2016). Control of dreissenid mussel infestations will require water treatment plants to alter their physical and chemical treatment methods (Connelly et al., 2007: Park & Hushak, 1999). These mussel mitigation measures are usually implemented at the intake structure and transmission pipe (Chakraborti et al., 2016).

In addition, water treatment plants may need to address the negative impacts dreissenid mussels can have on drinking water aesthetics. Geosmin, an odorous chemical produced by some species of algae and bacteria, impart earthy and musty odors to surface water (Colautti, Bailey, van Overdijk, Amundsen, & MacIssac, 2006). The pseudo feces produced by dreissenid mussels contain bacteria that produce geosmin; hence, sources of drinking water with mussel infestation typically require additional treatment to correct for undesirable tastes and odors.

Annual costs to water treatment plants were broken down by annual operation and maintenance (O&M) and construction (capital) costs to upgrade a facility. Hammond (2016) estimated the cost to keep a supply pipeline at a drinking water treatment plant free of zebra mussels for three chemical treatments: chlorine at $11.83 per million gallons (Mgal), potassium permanganate at $24.36 Mgal, and copper ions (EarthTec QZ™) at $20.00 Mgal. The cost of chlorine and potassium permanganate were used to estimate lower and upper bound damage estimates, respectively (Table 3). Chakraborti et al. (2016) presented costs for ten drinking water facilities actively managing for dreissenid mussel infestations. This study used their estimate of $154,670 in construction (capital) costs to upgrade a 1-Mgal/d water treatment facility to include chemical treatment for controlling dreissenid mussels plus an additional $3,000 per facility per year for power, pumping, and additional miscellaneous costs (Chakraborti et al., 2016).

Table 4. Potential Annual Mitigation Costs for Water Treatment Facilities

	Annual Withdrawals (Mgal) (a)	Average cost of chemicals (per Mgal) (b)	Additional O&M plus capital costs (c)	Annual Costs ((a × b) + c)
Lower Bound Estimate				
Montana	25,502	$11.83	($154,670 + $3,000) * 45	$7,397,000
Columbia River Basin	4,381		$157,670 * 11	$1,786,000
Missouri River Basin	21,121		$157,670 * 34	$5,611,000
Upper Bound Estimate				
Montana	25,502	$24.36	$157,670 * 45	$7,716,000
Columbia River Basin	4,381		$157,670 * 11	$1,841,000
Missouri River Basin	21,121		$157,670 * 34	$5,876,000

5.3 Thermoelectric, Mining, Industrial & Aquaculture

While seemingly unrelated, thermoelectric, mining, industrial and aquaculture are reviewed together due to the lack of current information on the economic damages these stakeholders may face if dreissenid mussels are present in Montana. To provide the most comprehensive accounting of the potential mitigation costs in Montana, the mitigation methods used by water treatment plants were assumed to be the most similar to the mitigation options these stakeholders would likely adopt. Brief descriptions of each stakeholder group are presented below.

Thermoelectric power plants generate electricity by boiling water to create steam to spin the turbines. Fossil fuels like coal, natural gas, or oil are burned to produce the heat that boils the water. Water withdrawals are used to cool the equipment used in the production of power. Just over half (55 percent) of Montana's net electricity generation comes five coal-fired power plants. Natural gas and petroleum coke each produce about 1.5 percent of Montana's net electricity generation (U.S. Energy Information Administration, 2018).

In mining, water is used in the extraction of coal, sand, gravel, and other ores; crude petroleum; and natural gas. The estimated value of nonfuel mineral production for Montana was $1.31 billion in 2013 (USGS, n.d.). In 2011, there were 309 mining operations employing over 9,000 individuals (Montana Mining Association, n.d.).

The industrial consumptive use category is broad and covers water use related to the production of wood products, such as pulp and paper, oil refining, sugar beet processing, and other industrial uses. Montana has four operating oil refineries in the eastern part of the state with a crude oil processing capacity of about 205,000 barrels per day. The refinery in Great Falls receives water from the city water department whereas water withdrawals for the remaining three refineries are accounted for in this category. Montana has two sugar processing factories that processed over 1.4 million tons of sugar beets in 2014.

Montana has 16 aquaculture facilities, both private and state-owned, engaged in the production of cold- and warm-water fish species for stocking or consumption purposes. Only two of these facilities, Fort Peck State Fish Hatchery and Miles City Fish Hatchery, would face mussel mitigation costs because of their source of surface water that supports hatchery operations. The other 14 facilities obtain surface water from springs or spring creeks.

There were no recent studies on the cost to thermoelectric plants or industry from dreissenid mussels impacts. In the late 1990s, two studies published data on costs to electric utilities (electric power plants) and industry that drew water from the zebra mussel-infested Great Lakes (Hushak & Deng, 1997; Park & Hushak, 1999). However, these studies were considered outdated. Similarly, cost information on mussel mitigation for mining and aquaculture were lacking. The methods used by water treatment plants to mitigate the presence of dreissenid mussels were assumed to be the most similar to the methods that these industries would likely adopt; therefore, the per volume cost calculated for water treatment plants – $290 to $303 per Mgal – were used in estimating the potential economic damages for these four industries (Tables 5 – 8).

Table 5. Potential Annual Mitigation Costs to Thermoelectric Facilities

	Annual Withdrawals (Mgal) (a)	Average cost (per Mgal) (b)	Annual Costs (a × b)
Lower Bound Estimate			
Statewide	27,339	$290	$7,930,000
Columbia River Basin	- -		--
Missouri River Basin	27,339		$7,930,000
Upper Bound Estimate			
Statewide	27,339	$303	$8,272,000
Columbia River Basin	- -		--
Missouri River Basin	27,339		$8,272,000

Table 6. Potential Annual Mitigation Costs to Mining Operations

	Annual Withdrawals (Mgal) (a)	Average cost (per Mgal) (b)	Annual Costs (a × b)
Lower Bound Estimate			
Montana	7,483	$290	$2,170,000
Columbia River Basin	3,285		$953,000
Missouri River Basin	4,198		$1,217,000
Upper Bound Estimate			
Montana	7,483	$303	$2,264,000
Columbia River Basin	3,285		$994,000
Missouri River Basin	4,198		$1,270,000

Table 7. Potential Annual Mitigation Costs to Industrial Facilities

	Annual Withdrawals (Mgal) (a)	Average cost (per Mgal) (b)	Annual Costs (a × b)
Lower Bound Estimate			
Montana	1,643	$290	$476,000
Columbia River Basin	183		$53,000
Missouri River Basin	1,460		$423,000
Upper Bound Estimate			
Montana	1,643	$303	$497,000
Columbia River Basin	183		$55,000
Missouri River Basin	1,460		$442,000

Table 8. Potential Annual Mitigation Costs to Aquaculture [1]

	Annual Withdrawals (Mgal) (a)	Average cost (per Mgal) (b)	Annual Costs (a × b)
Lower Bound Estimate			
Montana	548	$290	$159,000
Columbia River Basin	- -		--
Missouri River Basin	548		$159,000
Upper Bound Estimate			
Montana	548	$303	$166,000
Columbia River Basin	- -		--
Missouri River Basin	548		$166,000

[1] Adjusted to reflect only 2 of 16 facilities will face potential mitigation costs.

5.4 Domestic Self-Supplied

Self-supplied water use is water withdrawn from a groundwater or surface water source by an individual rather than coming from a public supply. The population of Montanans who are classified as self-supplied domestic users is roughly 304,000. Total self-supply withdrawals equaled 23.7 Mgal/d. Groundwater withdrawals accounted for 95 percent. The remaining five percent or 1.12 Mgal/d comes from surface water withdrawals (Deiter et al., 2018). Approximately 6,000 Montanan households supply their own domestic water needs from surface water.

In general, private residence water intake systems can be considered as consisting of two parts: an onshore component that includes the pump and distribution pipes to and within the house; and an offshore component, which is the pipe from its intake in the lake or river to the pump on the shore (O'Neill, 1993). In-line filtration is an easily accomplished control option for the onshore component of a residential water system. A filter capable of removing particles larger than 50 microns is needed in order to remove mussel veligers, which are approximately 70 μm in size (O'Neill, 1993). A whole house in-line filter rated for 50 μm can be purchased from Grainger for $76.50. Filters are expected to last 6 months depending on the amount of silt, algae, mussel veligers, and other material passing through the system. Replacement filters cost $15. Another option is to install an in-line chlorine injection system. The amount of chlorine added is comparable to that added to municipal drinking water for disinfection purposes while being sufficient to kill mussel veligers, juveniles and adults drawn into the system (O'Neill, 1993). The added benefit of this method is the improvement in taste and odor, which dreissenid mussels negatively affect. A chlorination system from the Clean Water Store costs approximately $500 per household. Converting to a per volume cost, the costs per Mg of water withdrawn were $1,345 and $7,348 for in-line filters and a chlorine injection system, respectively (Table 9).[1]

Several options are available for managing for dreissenid mussels in the offshore component including burying the intake in trenches filled with sand and gravel; using an enclosed, prefabricated sand filter; or periodic mechanical cleaning. The first two options are site specific and as such there are no published cost estimates for these options. The cost of the third option is the homeowner's time. The cost of the offshore component of a private residence water intake was not calculated for this study.

Table 9. Potential Annual Mitigation Costs to Private Residences with Domestic Self-Supply

	Annual Withdrawals (Mgal)	Cost per Mgal treated (b)	Costs (a × b)
Lower Bound Estimate – In-line filter			
Montana	408.8	$1,345	$550,000
Columbia River Basin	354.1		$476,000
Missouri River Basin	54.8		$74,000
Upper Bound Estimate – Chlorine injection system			
Montana	408.8	$7,348	$3,004,000
Columbia River Basin	354.1		$2,602,000
Missouri River Basin	54.8		$402,000

[1] The average Montanan household uses 186.4 gallons per day (gpd) based on an amount of water withdrawn by domestic users of 78 gpd per person (Montana Department of Natural Resources & Conservation, 2014) and the average household size in Montana of 2.39 people. The amount of water withdrawn for domestic self-supply equaled 1.12 Mgal/d serving approximately 6,008 households (1,120,000 gpd /186.4 gpd). Total costs of in-line filters or chlorine injection systems for 6,008 households divided by the volume of water withdrawn equals the per volume cost of each method.

5.5 Hydroelectric Power Generation

Montana has 26 hydroelectric facilities housing 78 generators that have the capacity to produce 2,685 megawatts (MW) of power (Blend, Martin, & Driscoll, 2014). Hydroelectric generation produces 30 to 40 percent of total generation (Blend et al., 2014). The following systems and equipment at hydroelectric facilities are at risk to be adversely impacted by invasive mussels: intake structures and trash racks, penstocks, gates and valves, cooling water systems, raw water fire protection systems, service and domestic water systems, and instrumentation (Boyd, 2016).

I evaluated three methods that span the spectrum of mussel mitigation approaches. The first method, ultra-violet light, addresses mussel impacts on internal components of the hydropower facility. The second method, foul-release coating, protects external components. These first two methods are at the upper end of direct cost investments. The third method is to manage the impacts mechanically through physical removal of the mussels. Although upfront costs are less, relying solely mechanical removal will likely result in more down time and higher labor and maintenance costs, translating into greater revenue losses. Following the approach used by Phillips, Darland and Sytsma (2005) total costs were converted to a per generator cost estimate.

The capital and O&M costs associated with mitigating dreissenid mussel impacts estimated here are based, in part, on cost estimates from Davis, Parker, and Hoover Dams on the Lower Colorado River (Boyd, 2016). Quagga mussels were discovered in Lake Mead in 2007. Subsequent inspections of facilities along the lower Colorado River revealed low-density populations of quagga mussels on external infrastructure at Hoover, Davis, and Parker Dams (Boyd, 2016). Reclamation, owner and operator of the dams, installed ultra-violet (UV) light systems and duplex strainers, among other mitigation strategies, to mitigate the impacts of quagga mussels on their facilities. Reclamation's capital and maintenance costs specific to quagga mussel mitigation from 2016 to 2020 was $3.8 million at Hoover Dam and $1.2 million at Davis Dam not including the cost of electricity to run the UV light system (Boyd, 2016).[2] Distributing the sum of these costs over the four generators at Davis Dam and the 17 generators at Hoover Dam results in a mussel mitigation cost over a five-year period of $230,558 per generator or $46,112 per generator per year. Pucherelli and Claudi (2017) tracked power consumption for a UV system to protect the cooling water of one Davis Dam generator at a UV dose level of 40 mW-s/cm^2. Their estimate of the annual cost of electricity was $3,150 to $4,350, averaging $3,750 per generator per year. Combining the capital, O&M, and average cost of electricity resulted in a mussel mitigation cost of $49,862 per generator per year (Table 10).

[2] I elected not to use the cost data for Parker Dam because Reclamation installed self-cleaning duplex strainers at this facility, which are considerably more expensive. In addition, the report did not specify the number of duplex strainers that were installed at Hoover Dam and Davis Dam.

A management option for submerged infrastructure is to apply foul-release coatings, which inhibit mussel attachment and growth. Silicone-based foul-release coatings are considered non-toxic and are effective against macrofouling (Wells & Sytsma, 2013). The downsides of foul-release coatings are cost and susceptibility to gouging (Wells & Sytsma, 2013). Potential applications include intake screens, drains, diffuser gratings and plates, trash racks, internal surfaces of large diameter piping, and fish passage facilities (Reclamation, 2015; Wells & Sytsma, 2013). The cost estimate for applying Sher-Release/Duplex foul-release coating system was $9.94 per square foot (Wells and Sytsma, 2013). This estimate included labor, equipment, supplies and other direct costs. The total surface area of trash racks at Davis and Hoover Dams is 209,500 square feet. At a cost of $9.94 per square foot, the total cost to apply foul-release coating would be $2.1 million or $94,656 per generator unit. Assuming trash racks would be painted every five years the cost estimate for foul-release coatings is $18,931 per generator per year (Table 11).

Mussel control can also be achieved by physically removing the mussels using mechanical means such as scraping, power washing, and cleaning. Mechanical activities are also necessary to remove mussel shell debris resulting from other control methods or natural die-off. In addition, operational activities such as drawdowns or desiccation will also reduce mussel populations. Relying solely on mechanical methods to mitigate for mussel-related impacts will likely result in additional shut downs not including the regularly scheduled shut downs for maintenance imposing costs from lost revenue generation.

The Chief Executive Officer, B. Lipscomb, of Energy Keepers, Inc., the owner/operator of Seli'š Ksanka Qlispe' (SKQ) dam on the Flathead River in northwest Montana estimated two weeks per quarter or eight weeks a year for additional downtime to mechanically remove mussels in the absence of other mitigation measures (personal communication, July 3, 2018). Generating 1.1 gigawatt hours annually, SKQ has an annual revenue stream of roughly $20 million assuming a price of $20 per megawatt hour (MWh). The additional eight weeks of downtime equates to a 10 percent reduction in power generation or a revenue loss of $2 million per year. A scenario-based approached was used to calculate the economic damages to hydropower as a result of additional generator downtime. The cost estimates were based on a 2 percent and 10 percent reduction in power generation with a market rate of $20 per MWh (Table 12).

The lower bound estimate of economic damages for hydropower facilities was a combination of costs for one UV light system and duplex strainers (similar in number to Davis and Hoover dams) per generator, foul-release coatings on trash racks, and a 2 percent reduction in power generation. The upper bound estimate was the 10 percent reduction in power generation.

Table 10. Potential Annual Mitigation Costs for Hydropower Facilities Adopting UV Light Systems with Duplex Strainers

	Number of generators (a)	Annual cost per generator (b)	Costs for UV + duplex strainers
Montana	78	$49,862	$3,889,000
Columbia River Basin	32		$1,596,000
Missouri River Basin	46		$2,294,000

Table 11. Potential Annual Mitigation Costs for Hydropower Facilities Applying Foul-Release Coating

	Number of generators (a)	Annual cost per generator (b)	Costs for trash rack foul-release coating (a × b)
Montana	78	$18,931	$1,477,000
Columbia River Basin	32		$606,000
Missouri River Basin	46		$871,000

Table 12. Potential Annual Mitigation Costs for Hydropower Facilities from Additional Generator Downtime

	2011 Net electric generation (million MWh)	Reduction in energy generation (MWh) (a)	Market price (MWh) (b)	Lost Revenue (a × b)
Lower Bound Estimate – 2% reduction in generation				
Montana	12.7	253,247	$20	$5,065,000
Columbia River Basin	7.8	156,430		$3,129,000
Missouri River Basin	4.8	96,817		$1,936,000
Upper Bound Estimate – 10% reduction in generation				
Montana	12.7	1,266,236	$20	$25,325,000
Columbia River Basin	7.8	782,149		$15,643,000
Missouri River Basin	4.8	484,087		$9,682,000

5.6 Recreational Boating & Fishing

Dreissenid mussels can attach to boat motors, hulls, and trailers. The degree of fouling depends on length of time a vessel remains in infested waters and the density of the mussel population. Veligers drawn into the engine can settle in the engine cooling system, and grow into adults causing the motor to overheat. Adult mussels attached to boat hulls can increase drag, reducing fuel efficiency, and damage the boat's finish. Boat owners can avoid these damages by storing the boat out of the water and allowing the boat to completely dry between uses. Estimates of additional boat maintenance expenses resulting from AIS in Lake Tahoe ranged from $200 to $400 per year per boat (USACE, 2009).

Boats in Montana are seasonally moored with owners winterizing and storing their boats in the off-season. The reduced exposure to mussel infested waters and the annual cleaning of a boat's hull and engine in preparation for winter storage should keep repair costs from dreissenid mussel damage minimal, thus the lower value of $200 per watercraft per year was used for this analysis (Table 13). In 2018, there were 69,575 registered watercraft with a motor in Montana (Stockwell, 2018). The Montana Department of Justice, Motor Vehicle Division (n.d.) tracks vehicle registration by vehicle type by county allowing for the estimation of the percentage of boats in the Columbia and Missouri River Basins, 47 percent and 53 percent, respectively.

Table 13. Potential Annual Mitigation Costs to Recreational Boaters

	Motorized Watercraft (a)	Maintenance costs per boat (b)	Recreational boating impacts (a × b)
Montana	69,757		$13,951,000
Columbia River Basin	32,786	$200	$6,557,000
Missouri River Basin	36,971		$7,394,000

Dreissenid mussels' impacts on the fish assemblage remains uncertain. Strayer, Hattala, and Kahne (2004) examined fish assemblages in the Hudson River after the zebra mussel invasion. The researchers found the effect depended on whether the fish feed on the edges of a lake or river (littoral species) or the fish feed heavily on food floating in the water column (open-water species). The open-water species declined, moving downriver away from the zebra mussel populations, whereas the littoral species increase shifting upriver. In a meta-analysis of existing research on the impacts from dreissenids, Higgins and Vander Zanden (2010) stated the responses of fish assemblages would depend on the extent of the ecological changes, and the ability of fishes to respond to these changes.

Lacking a clear understanding of the shift in Montana's fish species that might occur in the presence of dreissenid mussels, and hence, the impact on recreational fishing activity, a scenario-based approach was adopted. Similar to the study on the economic impact of AIS to recreational fishing in Lake Tahoe (USACE, 2009), this study assessed the economic damages associated with reductions in fishing effort. Montana Fish Wildlife and Parks (FWP) conducts periodic surveys of angler fishing days and the amount spent while on a fishing trip. Using estimated per day expenditures for resident anglers multiplied by the number of days of fishing, total angler expenditures for 2013 amounted to approximately $193 million (Swanson, 2016; Table 14). Non-resident spending on recreational fishing was also quantified; however, these expenditures would be captured in the tourism section so these estimates were not included here to avoid double counting. The percentage distribution of angler days between the Columbia and Missouri River Basins, 30 percent and 70 percent, respectively, was calculated using the most recent report on angling pressure by Montana FWP with Region 1 and 2 representing the Columbia River Basin and Regions 3 through 7 representing the Missouri River Basin (Selby, Hinz, & Skaar, 2017). A proportional relationship between angler spending and days of fishing was assumed for this analysis, meaning that a given percent reduction in the number of fishing days would result in the same percent reduction in spending. A lower and upper bound estimate of economic impact was estimated using a 2 percent and 10 percent reduction in fishing days, respectively (Table 15).

Table 14. Montana Resident Angler Expenditures in 2013

	Angler Days (a)	Expenditures Per Day (b)	Total Angler Expenditures (a × b)
River/stream	1,289,336	$80.51	$103,804,000
Lake/reservoir	1,008,605	$87.36	$88,112,000
Undesignated [1]	17,356	$83.94	$1,457,000
Total	2,315,297	$83.52	$193,373,000

Note:
[1] Expenditures per day for the undesignated category is the average of river and lake daily expenditures.

Table 15. Potential Annual Loss in Revenue from Reductions in Recreational Fishing - Montana Residents

	Percent Reduction in Fishing Days		
	2%	5%	10%
Montana	$3,867,000	$9,669,000	$19,337,000
Columbia River Basin	$1,160,000	$2,901,000	$5,801,000
Missouri River Basin	$2,707,000	$6,768,000	$13,536,000

5.7 Tourism

In 2017, 12.5 million visitors travelled to Montana spending $3.4 billion during their stay. Every dollar spent by a non-resident tourist has both a direct and indirect effect on the local economy. The combined economic impact of non-resident expenditures in 2017 totaled $4.7 billion (Grau, 2018). Since the focus of this study is on the impact of dreissenid mussels, tourism spending was limited to April through September, the time of year when visitors are traveling to Montana to engage in water-based activities. Non-resident visitor spending from April through September amounted to $2.5 billion (Grau, 2018). Spending by out-of-state visitors was furthered refined by limiting expenditures to those tourists who were attracted to Montana for its lakes (36 percent; Institute for Tourism & Recreation Research [ITRR], 2018). Thus, water-related non-resident tourist spending amounted to $890 million in 2017. Expenditures were distributed between the Columbia and Missouri River Basins using the percentage of nights visitors spent in Glacier County (40 percent), a travel region comprised of counties in northwest Montana that closely map to the counties in the Columbia River Basin (ITRR, 2018).

To date there are no studies estimating the impact of invasive mussels on tourism. Therefore, the same scenario-based approach used for recreational fishing was used to estimate the economic damages – 2 percent, 5 percent, and 10 percent reductions in visitation. Here again, tourism spending was assumed to be proportional to visitation. Table 16 shows a range of percent reductions in visitation and the corresponding reduction in spending. If visitation goes down by two percent, the most conservative scenario, the amount of money spent by non-resident visitors would decrease by $17.8 million, a half of a percent reduction in total tourist spending in 2017. At the 10 percent reduction in visitation, tourism spending would decrease by $89 million or 2.6 percent of total tourist spending in 2017. The 2 percent and 10 percent reductions in visitation were used for the lower and upper bound estimates, respectively.

Table 16. Potential Annual Loss in Revenue from Reduced Tourism

	Percent Reduction in Visitation		
	2%	5%	10%
Montana	$17,800,000	$44,500,000	$89,001,000
Columbia River Basin	$7,120,000	$17,800,000	$35,600,000
Missouri River Basin	$10,680,000	$26,700,000	$53,401,000

5.8 Property Values

Dreissenid mussels are considered ecosystem engineers (Jones, Lawton, & Shachak, 1994) because of their profound effects on lake and river ecosystem function and structure (Zhu, Fitzgerald, Mayer, Rudstam, & Mills, 2006). Most of the attendant alterations to a lake ecosystem adversely affect the lake's aesthetics, which in turn can lower surrounding property values. The invasive mussels are extremely efficient filter feeders, each adult mussel filtering about 1 liter per day of water (Snyder, Garton, & Brainard Hilgendorf, 1997), increasing water transparency and light penetration, decreasing organic matter, and increasing nitrogen and phosphorus concentrations (Zhu et al., 2006; Strayer, 2009). While increased water clarity is desirable, the increased light penetration has resulted in increased plant and algal growth in the nearshore environment (Zhu et al., 2006; Strayer et al., 2004), which is not desirable. Dreissenid mussels also preferentially feed on certain algae species while rejecting others, namely cyanobacteria (Vanderploeg et al., 2001). In low to moderate nutrient lakes, zebra mussel invasion has increased cyanobacterium biomass and microcystin concentrations (Knoll et al., 2008; Raikow, Sarnelle, Wilson, & Hamilton, 2004). As a consequence, blooms of cyanobacteria or "blue-green algae" have increased in the Great Lakes since the invasion of dreissenid mussels (Vanderploeg et al., 2001). Cyanobacterial toxins are potentially harmful to humans causing skin rashes and gastrointestinal illness (Knoll et al., 2008). Finally, the shells from dead dreissenid mussels wash ashore, smothering beaches and potentially injuring swimmers and other water recreationalists from cuts sustained from the shells' sharp edges.

The value of lakefront property is influenced by suite of factors including how clear a lake appears. However, the increased water clarity associated with dreissenid mussels may not influence lakefront property values in Montana to the extent predicted from research on the relationship between sales price and water quality. Visual perceptions of changes in water clarity are sensitive to the initial state of the lake (Smeltzer & Heiskary, 1990). Thus, a one-meter improvement in clarity in a murky lake will result in a greater increase in sales price than an equal improvement in clarity in an already clear lake (Michael, Boyle, & Bouchard, 2000; Poor, Boyle, Taylor, & Bouchard, 2001). Lakes in Montana, on average, exhibit exceptional water clarity (Angradi, Ringold, & Hall, 2018; Bigham Stephens et al., 2015). Over three quarters (78 percent) of total lakefront property value is associated with three lakes – Flathead Lake, Whitefish Lake, and Swan Lake. These three lakes have average Secchi depths, a measure of water clarity, of about 9 meters (30 feet). This depth of clarity suggests any improvement in light transmission arising from dreissenid mussels is unlikely to be perceived by the unaided human eye. The dreissenid mussel induced improvement in water clarity and its effect on lakeshore property values is further curtailed by the potential for increased algal growth in the nearshore environment, described above, which would diminish water transparency. Excess algal growth decreases the recreational and aesthetic benefits of a lake lowering surrounding property values (Michael et al., 2000). For these reasons, the improved water clarity from dreissenid mussels will unlikely be capitalized in lakefront property values in Montana and consequently, I did not consider it in this analysis of the potential economic impacts of these invasive mussels.

The effect of dreissenid mussels on property values has not been explicitly estimated; however, the economic impacts of invasive aquatic plants, algal blooms, and degraded water quality due to excess nutrients on home sale price have been well documented (Horsch & Lewis, 2009; Zhang & Boyle, 2010; Baron, Zhang, & Irwin, 2016; Walsh, Milon, & Scrogin, 2011; Bingham, Sinha, & Lupi, 2015; Ara, Irwin, & Haab, 2006). Therefore, I use these existing studies as a proxy to estimate the potential loss in value to lakefront property due to dreissenid mussel invasion. Using estimates on the effects of algal blooms and degraded water clarity on property value is reasonable given their association with dreissenid mussel invasion as described above. The studies on invasive aquatic plants, specifically Eurasian milfoil, is more nuanced. The two invasive species have a commonality when the consequences of invasion that are particular to property value are considered. The mutual effects include the speed at which invasion spreads after introduction, the quasi-irreversible nature of invasion (at most, the invasion may be contained but never undone), and the high uncertainty on the extent of negative impacts a priori to introduction.

Based on a review of the literature, summarized below, I elected to bracket the low and high end impacts to property values using the 5.8 percent and 10 percent reductions, respectively. Results from multiple studies in multiple states (Minnesota, New Hampshire and Maine) showed a 1-meter decrease in water clarity decreased property values from 3.1 to 8.6 percent with a median value of 5.8 percent (Jakus et al., 2013). In an assessment of the economic impact of harmful algal blooms to property values on Lake Erie, Bingham et al. (2015) used a 10 percent reduction in value to shoreline properties. A study of Ohio lakes found harmful algal blooms with microcystin levels in excess of 1 μg/L, the no-drinking threshold set by the World Health Organizations, reduced lakefront property values by 22 percent (Wolf & Klaiber, 2017). In northern Wisconsin, lakefront property values decreased by 8 percent, on average, after invasion of Eurasian milfoil (Horsch & Lewis 2009). The presence of milfoil and native aquatic vegetation in Vermont lakes decreased property value ranging from 0.3 percent to 16.4 percent depending on the degree of total macrophyte (aquatic plant) coverage (Zhang and Boyle, 2010).

Using property valuation data from the Montana Cadastral, a database of assessed property values completed by county governments, the total value of private lakefront property in Montana equaled nearly $5 billion (Montana State Library, 2018). Applying the 5.8 and 10 percent reductions to lakeshore properties in Montana would result in $288.5 and $497.4 million in property value impacts, respectively (Table 17). The State General Fund and county governments where the affected properties are located will also experience a decrease in property tax revenue from the lowered property values (Table 18). Property taxes are levied against the taxable portion of a property's value. In 2016, the tax rate for residential property was 1.35 percent of assessed value. The total amount of annual taxes owed on a residential property is equal to the taxable value of the property multiplied by the cumulative mills in which the property resides (Montana Department of Revenue, 2016). Predicted losses in property tax revenue from decreases in lakefront property value ranged from $2.2 to $3.8 million per year.

Table 17. Potential Property Value Impacts to Privately Owned Lakefront Parcels

	Assessed value of lakefront property (millions) (a)	Reduction in property value (%) (b)	Property value impacts (millions) (a × b)
Lower Bound Estimate			
Montana	$4,974	5.8%	$288.5
Columbia River Basin	$4,664		$270.5
Missouri River Basin	$310		$18.0
Upper Bound Estimate			
Montana	$4,974	10%	$497.4
Columbia River Basin	$4,664		$466.4
Missouri River Basin	$310		$31.0

Table 18. Potential Annual Loss in Property Tax Revenue

	Assessed value of lakefront property (millions)	Taxable Value[1]	Property tax revenue loss
Lower Bound Estimate – 5.8% reduction			
Montana	$4,974	$67,150,000	$2,190,000
Columbia River Basin	$4,664	$62,967,000	$2,055,000
Missouri River Basin	$310	$4,183,000	$135,000
Upper Bound Estimate – 10% reduction			
Montana	$4,974	$67,150,000	$3,776,000
Columbia River Basin	$4,664	$62,967,000	$3,543,000
Missouri River Basin	$310	$4,183,000	$232,000

[1] Taxable value is the portion of the property's value subject to mill levies. The tax rate for residential property in 2016 was 1.35 percent of assessed value.

5.9 Cost Summary

The potential economic damages if dreissenid mussels were to colonize all water bodies in Montana at densities similar to Lake Erie totaled $72.4 to $121.9 million in mitigation costs, $23.9 to $112.1 million in lost revenue, and $288.5 to $497.4 million in diminished property value (Table 19). The range of potential economic damages for the Columbia River Basin were $19.0 to $35.6 million in mitigation costs, $10.3 to $44.9 million in lost revenue, and $270.5 to $466.4 million in diminished property value (Table 20). Stakeholders in the Missouri River Basin would potentially incur economic damages of $53.4 to $86.2 million in mitigation costs, $13.5 to $67.2 million in lost revenue, and $18.0 to $31.0 million in diminished property value (Table 20).

Not including property value losses, the top three stakeholder groups facing the largest potential economic impacts from dreissenid mussel invasion were tourism, irrigation, and hydropower accounting for 60 to 75 percent of the total potential damages statewide (similar percentages were calculated for the two river basins). The same trio of stakeholders was evident for the two river basins with the exception of hydropower in the Missouri River Basin. Lost revenue from reduced fishing effort in the Missouri River Basin was the third largest economic impact followed by hydropower.

Tourism or more specifically, reductions in non-resident tourist spending, had the largest economic impact statewide and in both river basins. In 2017, visitors to Montana spent $3.8 billion. Limiting visitor expenditures to those who visited Montana between May and September and indicated they visited because of Montana's lakes, total expenditures equaled $890 million. Reductions in visitation due to the presence of dreissenid mussels resulted in potential statewide economic impacts ranging from $17.8 to $89.0 million compared to $7.1 to $35.6 million in the Columbia River Basin and $10.7 to $53.4 million in the Missouri River Basin.

Predicted potential cost to irrigators was among the highest due to the volume of water withdrawn by this user group. In 2017, surface water withdrawals for irrigation equaled 9,393 Mgal/d, an amount that far exceeds all other withdrawal quantities combined. Potential mitigation costs to irrigators equaled $29.3 to $60.5 million statewide, $25.4 to $52.6 million in the Missouri River Basin, and $3.8 to $7.9 million in the Columbia River Basin.

The potential cost of mitigation faced by hydropower facilities was third highest statewide ranging from $10.4 to $25.3 million per year. The lower bound cost estimates were roughly even between the two river basins at $5 million; however, at the upper bound of cost estimates the Columbia River Basin totaled $15.6 million compared to $9.7 million in the Missouri River Basin. The upper bound estimate is driven entirely by additional generator downtime to physically remove dreissenid mussels. In 2011, hydropower facilities in the Columbia River Basin produced 62 percent of net electric generation from hydropower for the state.

Impacts to private property values were an order of magnitude higher than all other potential costs combined ranging from $288.5 to $497.4 million statewide, $270.5 to $466.4 million in the Columbia River Basin, and $18.0 to $31.0 million in the Missouri River Basin. Economic impacts were highest in the Columbia River Basin because three lakes – Flathead Lake, Whitefish Lake, and Swan Lake – all of which reside in the Columbia River Basin, make up over three quarters of total private lakefront property value.

Table 19. Summary of Potential Damage Costs for Dreissenid Mussels Statewide

Stakeholder Group	Montana	
	Lower Bound	Upper Bound
Mitigation Costs - Annual		
Irrigation	$29,250,000	$60,499,000
Thermoelectric Power	$7,930,000	$8,272,000
Public Supply	$7,397,000	$7,716,000
Livestock	$93,000	$193,000
Mining	$2,170,000	$2,264,000
Industrial	$476,000	$497,000
Aquaculture	$159,000	$166,000
Self-Supply Domestic	$550,000	$3,004,000
Hydropower	$10,431,000	$25,325,000
Recreational Boating	$13,951,000	$13,951,000
Mitigation Cost Total	**$72,407,000**	**$121,887,000**
Lost Revenue - Annual		
Recreational Fishing	$3,867,000	$19,337,000
Tourism	$17,800,000	$89,001,000
Property Tax Revenue	$2,190,000	$3,776,000
Lost Revenue Total	**$23,857,000**	**$112,114,000**
Private Property		
Property Value Loss Total	**$288,498,000**	**$497,410,000**

Table 20. Summary of Potential Damage Costs for Dreissenid Mussels by River Basin

Stakeholder Group	Columbia River Basin		Missouri River Basin	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mitigation Costs - Annual				
Irrigation	$3,840,000	$7,942,000	$25,410,000	$52,557,000
Thermoelectric Power	--	--	$7,930,000	$8,272,000
Public Supply	$1,786,000	$1,841,000	$5,611,000	$5,876,000
Livestock	$7,000	$14,000	$86,000	$178,000
Mining	$953,000	$994,000	$1,217,000	$1,270,000
Industrial	$53,000	$55,000	$423,000	$442,000
Aquaculture	--	--	$159,000	$166,000
Self-Supply Domestic	$476,000	$2,602,000	$74,000	$402,000
Hydropower	$5,331,000	$15,643,000	$5,101,000	$9,682,000
Recreational Boating	$6,557,000	$6,557,000	$7,394,000	$7,394,000
Mitigation Cost Total	**$19,003,000**	**$35,648,000**	**$53,405,000**	**$86,239,000**
Lost Revenue - Annual				
Recreational Fishing	$1,160,000	$5,801,000	$2,707,000	$13,536,000
Tourism	$7,120,000	$35,600,000	$10,680,000	$53,401,000
Property Tax Revenue	$2,055,000	$3,543,000	$135,000	$232,000
Lost Revenue Total	**$10,335,000**	**$44,944,000**	**$13,522,000**	**$67,169,000**
Private Property				
Property Value Loss Total	**$270,527,000**	**$466,425,000**	**$17,971,000**	**$30,984,000**

Note: River Basin totals don't add to statewide total due to rounding.

6. Discussion

6.1. Predicted Economic Damages

This study provided predictions of the potential economic impacts to various stakeholder groups in Montana, a state with a single confirmed detection of mussel veligers but, as yet, no viable adult populations. Further, these estimates were scaled to the two major river basins in the state, the Columbia and the Missouri. The predicted economic impacts presented herein consisted of mitigation costs, lost revenue, and diminished property value. The first two costs are annual while the third represents a single episode of lost value. Mitigation strategies were predicted to cost stakeholders between $72.4 and $121.9 million annually; potential reductions in revenue due to lower rates of participation and diminished property value ranged from $23.9 to $112.1 million. A similar study on the potential economic damages to Idaho, the western neighbor of Montana and also mussel-free, amounted to $94.5 million (Idaho Aquatic Nuisance Species Taskforce, 2009). Lower bound estimates calculated for Montana were roughly equivalent and upper bound estimates were roughly double; however, Idaho's estimates did not include impacts to property tax revenue nor costs to irrigators.

Not surprisingly, the stakeholders with the largest potential economic costs were property owners with lakefront parcels amounting to $288.5 to $497.4 million statewide. These losses will not only be faced by homeowners with lake front parcels but also the State's general fund and local county governments in which the properties reside due to the associated decline in property tax revenue. The predicted loss in property tax revenue ranged from $2.2 to $3.8 million annually. Local government and school district tax collections come almost entirely from property taxes (96.4 percent; Montana Department of Revenue, 2016), thus the impact will be substantial. The magnitude of loss is driven by the price premium for lakefront real estate especially along Flathead Lake, Whitefish Lake, and Swan Lake. The value of lakefront property at these three lakes amounted to 78 percent of the total lakefront property value statewide. Lake Tahoe, situated along the border between California and Nevada, is also mussel-free but does have other AIS including Asian clams, Eurasian watermilfoil and curly leaf pondweed. As part of the AIS Management Plan for Lake Tahoe, the impact to property values from AIS was assessed using existing literature (USACE, 2009). The studies selected to estimate losses in property value were based on the presence of Eurasian watermilfoil and water clarity as measured by Secchi depth. Property along the shores of Lake Tahoe was valued at $4,842 million and estimated property value losses from AIS amounted to $261.5 to $968.5 million. Reductions in property value to lake front parcels in Montana were similarly valued at $288.5 to $497.4 million.

6.2 Practicality of Approach for Estimating Costs

The approach developed for and used in this study is based on the extrapolation of mussel mitigation costs experienced by stakeholders in regions currently invaded by dreissenid mussels. The framework is sufficiently general that it is reasonably straightforward to apply to other jurisdictions where dreissenid mussels are a concern. Importantly primary data collection is not required, a likely concern for managers with small budgets. A researcher could choose to apply the per volume/unit cost estimates or percent reductions in participation/value provided herein to information specific to their locality. As previously mentioned, USGS estimates surface water withdrawals for every state and by county. Data on non-consumptive uses are also publicly available. Information on hydropower facilities is available from the U.S. Energy Information Administration, for instance. Equally accessible are estimates of expenditures by fishermen and tourists, the number of boats registered in a state, and property values. The per volume/unit cost estimates can also be updated with new cost studies or expanded to include more mitigation options.

6.3 Usefulness of Results to Managers

Equipped with the evidence of costs provided herein, managers can demonstrate to decision makers the costs of *no action* highlighting the potential economic damages to a wide range of stakeholders across the state and in specific regions. Crucially this study illustrates the stakeholders who will face the greatest costs should dreissenid mussels become established. The current level of Montana's AIS funding, approximately $6.5 million, is roughly 7 percent of the lower bound estimate of $96.3 million, the sum of potential mitigation costs and lost revenue. Funding for Montana's AIS program supports public education, monitoring, watercraft inspection program, and enforcement – essential elements in the fight against the continued spread of dreissenid mussels. Prevention and early detection and rapid response (EDRR) are considered the most cost-efficient approaches to minimizing the economic damages of dreissenid mussels and other AIS (Cusack et al., 2009). Once established, adult dreissenid mussels can not be eradicated leaving damage mitigation and control as the only feasible and more costly policy responses. Stable, long-term funding is essential for preventing new introductions and containing existing detections.

6.4 Embracing Total Economic Value

The potential economic damages reported on here do not include the cost of lost ecosystem function and associated services nor the values society holds for knowing an ecosystem exists (existence value) and leaving a well functioning ecosystem for future generations (bequest value), collectively known as non-use values. Nonmarket valuation studies, which measure non-use values, are resource intensive and as such have yet to be completed to explicitly measure the reduction in non-use values due to the ecological impacts of dreissenid mussels. Although, for a comprehensive accounting of losses to human welfare, nonmarket values must be incorporated (Leung et al., 2002; Larsen et al., 2001). Therefore, the potential impacts presented here and elsewhere are likely underestimates of the total economic value of the impacts caused by dreissenid mussels. In fact, in some instances, such as the invasion of the Columbia River Basin, researchers have stated that the ecological costs could be much larger than the direct costs (Independent Economic Analysis Board, 2013).

As argued by others (Leung et al., 2002; Bossenbroek et al., 2009; Strayer, 2009; Cusack et al., 2009) the economics of dreissenid mussel impacts must go beyond the financial accounting of damage and control costs and include the estimation of impacts on total economic value and the consequences to human welfare from the loss or impairment of ecosystem function and the services that benefit humans. Knowing and communicating the true economic impacts of invasion are likely key to preventing the spread of invasive mussels. Preventing dreissenid mussel introduction into the Columbia River Basin, the last major river basin in the continental U.S. that remains mussel-free, is a major priority described in the Quagga-Zebra Action Plan (2010) by the Western Regional Panel on Aquatic Nuisance Species. An assessment of the nonmarket impacts of dreissenid mussels seems overdue and quite necessary if the socially optimal level of funding for prevention programs is to be a goal.

7. References

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Figure 1. Columbia and Missouri River Basins in Montana