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Benefit-Cost Analysis of Municipal Rural and Industrial System on Crow Reservation Montana

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Abstract

There is currently little research about the economic outcomes for tribes that settle their water rights with the United States. To address this gap, I conduct a benefit-cost analysis on the Crow Reservation's Municipal, Rural, and Industrial System funded by the Crow Tribe Water Rights Settlement Act of 2010. This project is designed to revitalize the existing community water systems on Crow Reservation and provide community water access to over half of the reservation's residents that otherwise rely on wells, springs, or hauling water. I also discuss the implications this may have for tribes unable or ineligible to settle water rights. Based on the baseline scenario of the cost-benefit model, the benefits of this system accumulate to $413 million (95% CI $339 million - $508 million) at a 3 percent discount rate, $1,464 (95% CI $1,261 million - $1,776 million) at a 0.1 percent discount rate, and $153 million (95% CI $115 million - $194 million) at a 7 percent discount rate. Costs accumulate to $320 million at a 3 percent discount rate, $632 million at a 0.1 percent discount rate, and $196 million at a 7 percent discount rate. The respective benefit-cost ratio for each discount rate is 1.29, 2.31, and 0.78.

Contents

Introduction

By the early 1900s, communities around the US had collectively invested billions of dollars into drinking water technology and infrastructure. This investment shortly corresponded with a decline in waterborne infectious diseases and subsequently lengthened life spans (Sedlak, 2019). By the 1940s, roughly half of all homes in the US had access to complete plumbing. This statistic accelerated quickly as by the 1950s, two-thirds of all homes had complete plumbing, and by the 1960s, five of every six homes had complete plumbing. In 1990 only 1% of households went without complete plumbing, but 22% still lacked access to a community water system with no record of violations of health-based standards (US Census Bureau, 2021; US Environmental Protection Agency, 2022). By the early 2000s, this statistic decreased to as little as 6.4%, but since then, access to community water systems without health-based violations has leveled off. As of 2021, 7.6% of people in the US did not have access to a reliable community water system, and 0.65%, or 2.2 million, still lacked plumbing (Roller et al., 2019; US Environmental Protection Agency, 2022).

Despite significant progress in improving water access through plumbing and safe drinking water, a persistent gap remains in the United States. While low-income communities and communities of color are more likely to have inadequate water access, race is the single most significant predictor of adequate water and sanitation access. Nationally, 0.3 percent of white households, 0.5 percent of African American and Latino households, and 5.8 percent of Native American households lack access to complete plumbing (Roller et al., 2019). These statistics are significant as inadequate drinking water contributes to higher unemployment and mortality rates on reservations than in adjacent non-Indian communities with water access (Western States Water Council & Native American Rights Fund, 2014). Many tribes are working to address these disparities by settling Indian Water Rights Settlements, which can provide funding for critical water infrastructure in tribal communities (Stern, 2022).

Research Objective

Although highly consequential for many tribes, research on the economic impact of Indian water rights settlements remains extremely limited. In this paper, I aim to build and comment on existing literature by Sanchez et al. (2022), virtually the only recent literature on the long-term economic outcomes of Indian water rights settlements. To do so, I conduct a benefit-cost analysis of the regional benefits of the Crow Reservation's Municipal, Rural & Industrial system funded through the Crow Tribe Water Rights Settlement Act of 2010. The analysis emphasizes examining benefits, compared to costs, as benefits are far more uncertain.

As I use back-of-the-envelope style calculations for many factors and do not quantify benefits realized outside of the Crow Reservation, highly uncertain benefits, or unquantifiable benefits, I do not intend this analysis to be used as a legitimate reference for all benefits realized from the Crow MR&I system or other Indian water right settlement cases. Furthermore, my findings apply to reservations residents as a whole and not necessarily to Crow Nation members. Therefore instead, I use my result to speak to the importance of funds in water settlement cases, the short fallings of water settlements, and the implication for tribes that do not have significant water settlement cases to leverage for essential funding.

Historical Context

During colonial expansion, western states in the US first adopted the prior appropriation water rights system, diverging from the riparian rights systems the rest of the US relied on. California was the first state to adopt a prior appropriation water rights system in 1855 when the state's Supreme Court ruled in favor of senior rights user and plaintiff Irwin in Irwin v. Philips.

Ruling in a civil suit between miners, the court ruling followed the ‘first in time, first in right’ rule mining towns used to allocate water rights (Wilkinson, 2006). Contrary to common law riparian rights, where all landowners adjacent to a body of water have water rights, the prior appropriation doctrine allocates the senior appropriator full rights to water first diverted and applied to beneficial use (Irwin v. Phillips, 1855). During this time, prior appropriation encouraged investment by ensuring investors would hold a claim to water they could put to beneficial use. Between 1855 and 1890, all seventeen continuous states on or west of the 100th meridian, which runs through North Dakota down through Texas, adopted versions of prior appropriation to govern water rights (Leonard & Libecap, 2016). However, a few states have modified their laws to varying degrees over the past century to include a hybrid of appropriation and riparian rights systems (Welden, 2003).

As demand for water began to outpace accessible supply, new water rights claims and western settlement slowed in the late 19th century, pressuring Congress to invest in irrigation projects to encourage further settlement (Leonard & Libecap, 2016; US Bureau of Reclamation, 2018). Until then, the federal government had little involvement in water infrastructure development as state-controlled water rights. With bipartisan support in 1902, Congress created the Bureau of Reclamation (Reclamation) with the Reclamation Act (Stern & Normand, 2020; US Bureau of Reclamation, 2018). Funded by Congress through sales of public lands, including reservation lands, the first Reclamation projects emphasized single-purpose irrigation development on arid land, which enabled primarily non-indigenous settlers to irrigate western lands. (Taylor, 2022; Stern & Normand, 2020). While the Reclamation Act symbolized the first significant federal involvement in western water, the act simultaneously reaffirmed state control of western water law. Section eight of the act lays out that states and territories would still "control, appropriation, use or distribution of water used in irrigation, or any vested right acquired … [and the federal government] in carrying out the provision of the act, shall proceed in conformity with such laws" (The Reclamation Act, 1902).

Under the prior appropriation system, reservations' water rights remained unclear. That came to a head in Winters v. United States, where the United States, as trustee to the Fort Belknap reservation, sued upstream users for excessive water consumption that effectively depleted Fort Belknap's supply to irrigate arid lands. Initially decided in a district court, the Supreme Court held that in creating the Fort Belknap reservation, the United States implicitly guaranteed the tribe enough water rights to fulfill the reservation's purpose, despite water shortages in the region (Winters v. United States, 1908). As tribes' claim to water dated back to the signing of treaties, tribes typically held more senior rights than non-indigenous users that had recently made claims (Brougher, 2011). While the ruling applied to all reservation lands, individual states did not have the same legal trust obligations to tribes as the federal government. The discrepancy in responsibility to tribes enabled states to ignore tribes' claims for water rights for decades following Winters (Sanchez et al., 2020). Furthermore, the Winters doctrine only specified that tribes are entitled to water rights necessary to satisfy the reservation's purpose but delegated water rights quantification to future judicial interpretation (Brougher, 2011).

Establishing Water Rights

Although the Winters ruling came down in 1908, tribal water rights remained unquantified until decades later. In Arizona v. California, the Supreme Court apportioned water rights to lower Colorado River basin states. The court also stipulated that tribes are entitled to a water quantity sufficient to irrigate all "practicably irrigable acres" (Arizona v. California, 1963). This means of quantification helped guide water rights adjudications moving forward, particularly for tribes with treaties that specified agriculture as a primary purpose of the reservation. However, the adjudication process for tribes is still often costly, lengthy, and complex. As of 2022, 46 tribes have completed adjudications, another 23 have initiated but not completed the process, and 145 tribes with eligible cases have not begun the process (Sanchez et al., 2022).

In adjudicating water rights, tribes can litigate their cases or settle them. Both litigation and settlements serve to quantify a tribe's water rights (Stern, 2022). The Department of Interior (DOI) regards litigation as a more costly, timely, and uncertain process for all parties. In settling, tribes often have access to other provisions, such as funding for water infrastructure, rights to lease water to off-reservation entities, or environmental protections that would not be available in the litigation process. Such provisions are often essential for tribes to turn their “paper water” or legal rights into “wet water” or tangible rights (Addressing the Needs of Native Communities through Indian Water Rights Settlements, 2015; Sanchez et al., 2022; Stern, 2022). The settlement process can also include non-federal stakeholder involvement and funding, although that varies widely between settlement cases.

Settlement agreements initially appear to reflect the cooperative bargaining theory, where two parties cooperate in settling a dispute to create an economic surplus that would not occur under uncooperative bargaining (Cooter & Ulen, 2012). However, the power in these negotiations is grossly imbalanced. In settlement cases, tribes typically agree to negotiate lower water rights claims in exchange for essential economic funding (Stern, 2022). While tribes that settle ultimately benefit from settlements, the federal government has long provided disproportionately lesser amounts of critical service funding for Native Americans in comparison to other populations (US Commission on Civil Rights, 2003). This is all in spite of the federal trust responsibility, in which the federal government takes on the responsibility to promote the autonomy of tribes and support their economic development via signing treaties, statutes, and historical relations with tribes (US Commission on Civil Rights, 2018).

Arguably, the federal government does this as they have a substantial conflict of interest within these settlement negotiations. In 1973, the Nation Water Commission recognized that many stakeholders, including the federal government, had invested billions of dollars into western water infrastructure that almost exclusively benefits non-indigenous water users (McElroy, 1986). At this time, it was presumably obvious that non-tribal stakeholders had much to lose from tribes claiming water rights. Soon after, in 1978, the Ak-Chin Indian Community became the first to settle their water rights (Secretary’s Indian Water Rights Office, 2021). In settling, the Ak-Chin Indian Community agreed to waive current and future claims to groundwater in exchange for rights to 85,000 acre-feet of water annually and “the construction of a well field and water delivery system” (An Act, 1978). Since then, the federal government has continued to leverage essential funding for water infrastructure and other forms of economic development to negotiate lower water rights claims from tribes.

Since 1990, the Department of Interior has encouraged tribes to settle their water rights claims instead of litigating them, but the process is still lengthy and costly for tribes, with implementation timelines stretching the process even further (Democratic Staff of the House Committee on Natural Resources, 2016; Stern, 2022). The majority of tribes do settle. As of late 2021, 38 tribes have concluded settlements, with 34 enacted by Congress and four administratively approved (Secretary’s Indian Water Rights Office, 2021). Twenty tribes are still in the negotiation process, which takes at least several years but can take up to decades in many cases (Sanchez et al., 2020; Stern, 2022). Most consequentially, 145 eligible tribes have yet to initiate a claim. While the rationale for not doing so likely varies between tribes, high legal fees and uncertain outcomes likely deter many smaller tribes from participating (Sanchez et al., 2022). However, ultimately, in not settling or being unable to settle, tribes miss out on the substantial economic investments the federal government allocates to tribes able to settle. Moreover, as settlements are often partially or wholly reliant on discretionary federal funding, it can take the federal government decades to implement settlement provisions, even when those provisions are necessary for tribes to fully use their water rights (Democratic Staff of the House Committee on Natural Resources, 2016; Stern, 2022).

Water Rights on the Crow Reservation

With two rivers running through the center of the Crow Reservation, water has been and continues to be an essential part of the economic, physical, mental, cultural, and spiritual well-being of the Crow Tribe (Doyle et al., 2018). The Crow Reservation, home to the Apsáalooke people, is situated on 2.3 million acres in south-central Montana. There are roughly 11,000 members of the Crow Nation: approximately 7,900 live on or near the Reservation (Office of the Governor Indian Affairs, n.d.). Elder Tribal members living on the Reservation can recount how water quality and quantity on the rivers have degraded since the 1960s with the expansion of non-Tribal agriculture both on the Reservation and upstream. Following this degradation, many rural Tribal households previously reliant on the rivers for water switched to domestic wells (Doyle et al., 2018).

Public health and environmental experts have long acknowledged the link between water quality and public health. However, in recent years, they have increasingly recognized the contribution of racial and income gaps to disparities in water access and quality for marginalized communities (VanDerslice, 2011). This holds for indigenous communities, as recent estimates assume that as many as 48% of all households on tribal lands lack access to clean drinking water or sufficient sanitation (Democratic Staff of the House Committee on Natural Resources, 2016). On the Crow Reservation, many rural water systems are over 40 years old and still need to be updated to meet current safe water drinking standards (Bureau of Reclamation, 2017). These water supplies face inadequate capacity, poor facility conditions, groundwater limitations, low water pressure, and inadequate water storage. However, the current water systems do not serve a majority of residents on the reservation. Unserved residences, therefore, typically rely on wells, hauling water, natural springs, or other sources (US Bureau of Reclamation et al., 2016). These sources host many other issues for residents as hauling water is often costly and overly burdensome to individuals, officials seldom monitor the water quality in wells or other sources, and households lack generational or community-based knowledge for well stewardship (Martin et al., 2021).

Members of the Crow Nation have long been aware of these issues, forming the Apsaálooke Water and Wastewater Authority (AWWWA) and the Crow Environmental Health Steering Committee (CEHSC) to research and address water quality on the reservation. Independent of the water rights settlements, AWWWA and CEHSC worked with other partners to secure $20 million in federal, state, county, and tribal grants. The groups used this funding to improve water access by replacing a failing sewage lagoon, old water and wastewater lines, wastewater connections to local schools, 19 broken fire hydrants, and creating a system to provide town water at a low cost to community members (Doyle et al., 2018; Eggers et al., 2018). While the grants provided funding for critical issues, $20 million alone is nowhere near enough to address the reservation-wide water quality and access issues.

The Crow Tribe Water Rights Settlement Act of 2010 established the Crow Nations' right to 650,000 Acre Feet per Year (AFY) and authorized $460 million in federal spending for water infrastructure development. However, the settlement process took decades, and implementation will take decades more. The Crow Nation initiated litigation efforts in 1975 and began negotiations in the 1980s. The 2010 settlement stipulates a lengthy implementation timeline with the federal government appropriating funding through 2030. In total, it will have taken the Crow Nation 55 years to negotiate and implement their water settlement (US Department of the Interior, 2012).

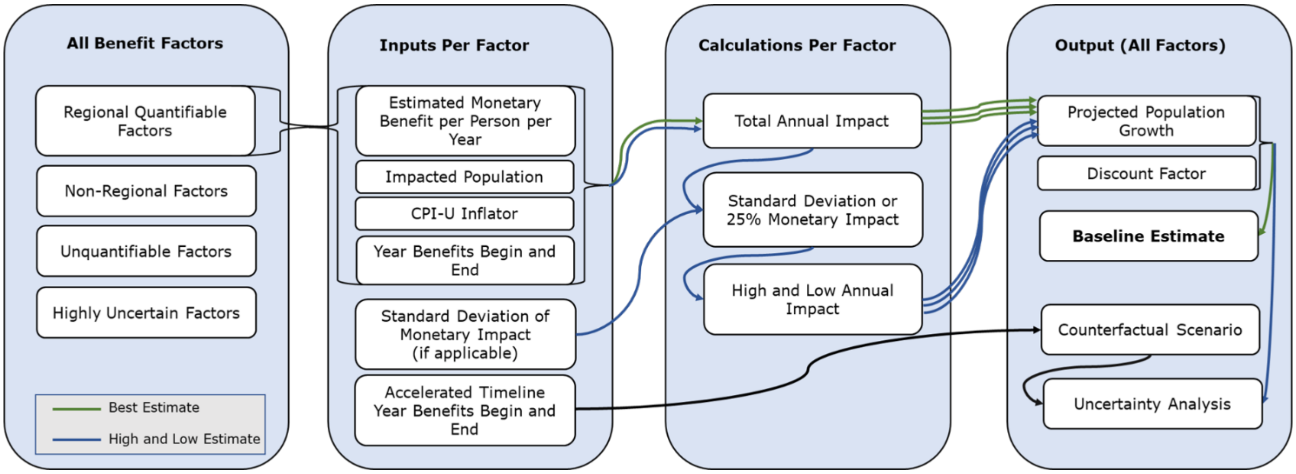
Of the total, the settlement designated $246,381,000 to construct the municipal, rural, and industrial (MR&I) water system and allocated an additional $47,000,000 for system operation, maintenance, and repair (OM&R). The settlement also authorized $131,843,000 for rehabilitating and improving the Crow Irrigation Project (CIP), $10,000,000 for OM&R of the CIP, $4,776,000 for tribal compact administration, and $20,000,000 for energy development projects. All funds indexed to May 1st, 2008 (Claims Resolution Act, 2010).

In 1975, Congress enacted Public Law 93-368. The law is aimed to improve “Tribal-Self Governance” by assuring that Indigenous Nations have meaningful and effective input in the “direction, planning, conduct and administration of contractible programs, functions, services, and activities” (US Bureau of Reclamation, 2020). In a broad context, Indigenous Nations can use 638 contracts for many applications. Within the context of water rights settlements, the law gives Indigenous Nations more autonomy to manage funding for projects. For the Crow Nation, the Secretary of the Treasury (Treasury) transferred all mandatory funding to the Nation for management under contract. As negotiations enabled an early transfer of all mandatory funding, the Crow Nation has managed all mandatory funding for the MR&I and CIP since 2011. The Treasury still updates funding indies based on inflation[1].

Methods

To calculate the benefit-cost ratio of the MR&I system on the Crow Reservation over 100 years, from the date of enactment in 2010, I (1) account reported federal investment in the project as costs, (2) estimate 38 known and quantifiable health and economic factors, both direct and indirect, (3) index all funds to 2022 (4) establish years cost and benefits begin and end, (5) account for projected population growth, and (6) apply three different discount rates. I also ran a counterfactual scenario with an accelerated investment and construction timeline and conducted an uncertainty analysis—reference Figure 1.

Figure 1: Benefits Model



I use the CPI-U as the inflator for benefits and the initially proposed construction timeline. I index all benefit factors to 2022 using the CIP-U, as it is the broadest inflation index, and the Bureau of Labor Statistics does not publish a consumer price index for rural consumers. I

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[1] I was originally hoping to learn more about the 638-contract process as there is little research about it, however I was not able to get in contract with anyone from the Crow Nation to learn more about how the contracts operate.

do not apply this same index to cost factors as the Reclamation adjusts them based on "construction cost indices applicable to the types of construction involved in the rehabilitation and improvement" of the MR&I system (Claims Resolution Act, 2010). Therefore, I rely on the Reclamations index of funds to 2022, which is slightly lower than the CIP-U inflator (US Bureau of Reclamation, 2021). For the construction timeline, I use the timeline detailed by Bartlett and West Engineering (2015), as this is the most recent timeline seemingly publicly available. However, it is important to note that recent budget reports indicate construction has fallen behind this timeline (Bureau of Reclamation, 2021). Therefore, the benefit-cost analysis will better represent the hypothetical timeline than the actual construction of the MR&I system.

I use discount rates of 0.1, 3, and 7 percent. I opted for three different discount rates as the Office of Management and Budget (OMB) advises federal agencies to conduct analyses with a 3 and 7 percent discount rate, where 3 percent represents the social rate of time preference and 7 percent represents the social opportunity cost of capital. However, some economists argue that these discount rates are outdated and no longer representative of either objective, as OMB last updated them in 2003 (Obama White House Council of Economic Advisers, 2017). I also include a discount rate of 0.1 percent, as economist Nicholas Stern endorses in his Economics of Climate Change report for the United Kingdom. Although this discount rate is unconventional, Stern argues it more accurately represents how economists should view the social discount rate of environmental benefits for future generations (Stern, 2006). I primarily rely on the 3 percent discount rate in discussing results as it best represents social discounting from a whole-society perspective (US Environmental Protection Agency, 2010).

Costs

The Crow Tribe Water Rights Settlement Act of 2010 defines federal spending on the MR&I project and therefore projects how much the Crow Nation will spend on constructing the system. The Act appropriates $146,000,000 in mandatory funding and $100,381,000 in discretionary funding for constructing the MR&I system. The settlement further stipulates that the federal government will index all funds to May 1, 2008, based on "applicable to the types of construction involved in the design and construction of the MR&I System" (Claims Resolution Act, 2010). The Secretary of the Treasury appropriated all mandatory funding to the Reclamation, including funds indexed back to 2008 in Fiscal Year 2011. Under the 638-contract, the Reclamation transferred all funds to the Crow Nation for management (US Bureau of Reclamation, 2012).

Beyond the initial mandatory funding, Reclamation allocates discretionary funds and required index adjustments on mandatory funding each fiscal year. While the Budget Justification documents differentiate between mandatory and discretionary funding streams, they do not differentiate between funding for the MR&I opposed to the CIP. To account for this, I scale all funds to the MR&I percentage of allocations. This is roughly 66.4% for all mandatory funds and 63.4% for all discretionary funds (Claims Resolution Act, 2010). Furthermore, I rely on Reclamation's adjustment to 2022 dollars from the initial settlement amount indexed to 2008 (US Bureau of Reclamation, 2021). As spending information on the construction project is not publicly available, I estimate that the Crow Nation will spend equal funds from both mandatory and discretionary streams during each year of the 20-year construction timeline. This is a rough estimate for discount purposes, and the accurate spending timeline would look different. Refer to Table 1: Estimated Annual Spending on MR&I System (undiscounted, 2022 dollars).

The Crow Tribe Water Rights Settlement Act of 2010 appropriates $47,000,000 for the OM&R fund. However, the funds alone will not cover the costs of operating and maintaining the system. OM&R costs for the system will begin in 2018 and increase through the end of construction in 2030. Annual costs cap off at roughly $6 million (Bartlett & West Engineering et al., 2015). However, as the current system, which serves roughly half of the residence on the reservation, would still require OM&R regardless of the construction of the full MR&I system, I attribute only half of projected OM&R costs to the MR&I system, assuming the Crow Nation would incur the other half regardless (US Bureau of Reclamation et al., 2016). This is a rough estimate.

Equation (1) is a basis for calculating the annual cost of constructing and operating the MR&I system. This equation calculates mandatory and discretionary funding with federal funds indexed to 2022 divided by the 20 years the system will take to construct. OM&R funds are half of the cost projected by Bartlett & West Engineering. Note that there are no mandatory or discretionary funds spent on construction after year 20.

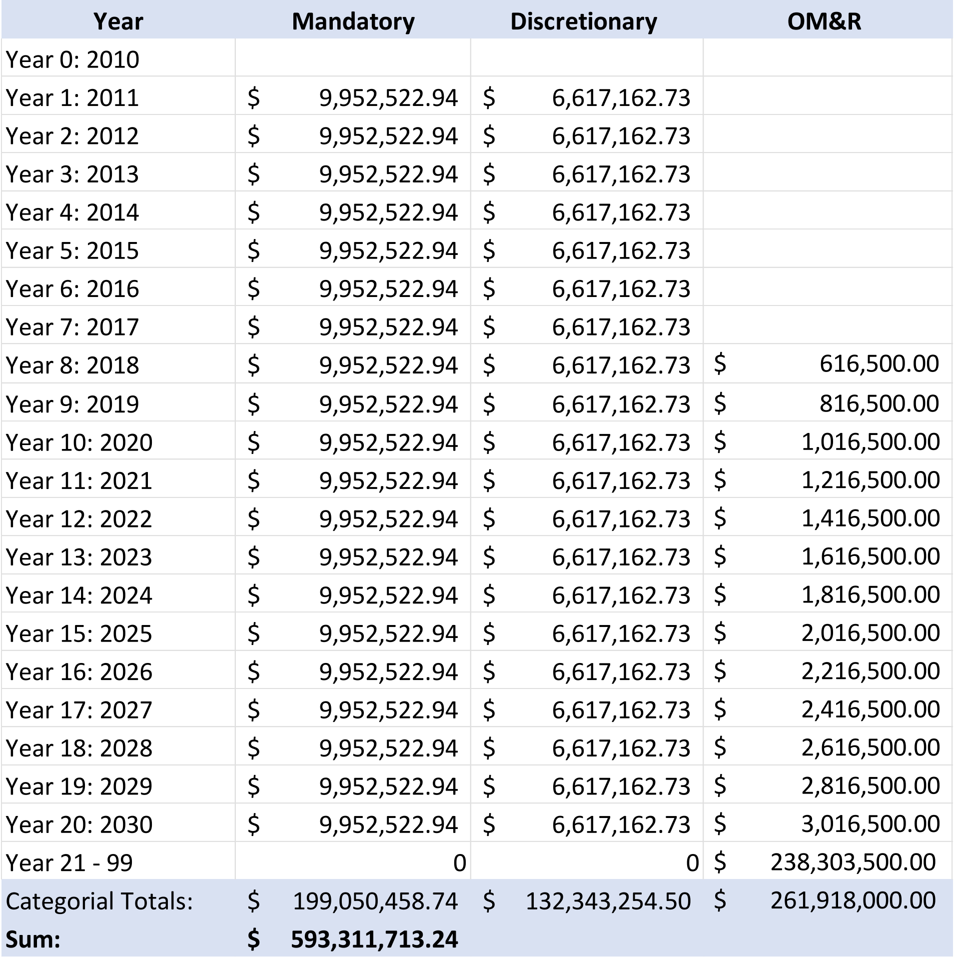
Equation (1): Annual Cost Estimation Equation

$$ATAC = (1/((1+r)^{Y})) \times (MF+DF+OMRF) \times ((1+((9050/6863)^{(1/50)} - 1))^{Y})$$

Where ATAB=Adjusted Total Annual Cost, r=Discount Rate, Y=Year of Cost Calculation, MF= Mandatory Funding, DF=Discretionary Funding, OMRF= Operation Maintenance and Repair Funding.

Finally, in calculating costs, I exclusively consider the construction and operation costs of the system. I do not account for any alternative investments made in the community because of the MR&I system that may bolster economic activity, as neither the Crow Nation nor other businesses have identified investments they may make in the community after the completion of the system. However, there may be other private or public investments in response to the system; therefore, actual costs and benefits may be underestimated.

Table 1: Estimated Annual Spending on MR&I System (undiscounted, 2022 dollars)



Year	Mandatory	Discretionary	OM&R
Year 0: 2010			
Year 1: 2011	$ 9,952,522.94	$ 6,617,162.73	
Year 2: 2012	$ 9,952,522.94	$ 6,617,162.73	
Year 3: 2013	$ 9,952,522.94	$ 6,617,162.73	
Year 4: 2014	$ 9,952,522.94	$ 6,617,162.73	
Year 5: 2015	$ 9,952,522.94	$ 6,617,162.73	
Year 6: 2016	$ 9,952,522.94	$ 6,617,162.73	
Year 7: 2017	$ 9,952,522.94	$ 6,617,162.73	
Year 8: 2018	$ 9,952,522.94	$ 6,617,162.73	$ 616,500.00
Year 9: 2019	$ 9,952,522.94	$ 6,617,162.73	$ 816,500.00
Year 10: 2020	$ 9,952,522.94	$ 6,617,162.73	$ 1,016,500.00
Year 11: 2021	$ 9,952,522.94	$ 6,617,162.73	$ 1,216,500.00
Year 12: 2022	$ 9,952,522.94	$ 6,617,162.73	$ 1,416,500.00
Year 13: 2023	$ 9,952,522.94	$ 6,617,162.73	$ 1,616,500.00
Year 14: 2024	$ 9,952,522.94	$ 6,617,162.73	$ 1,816,500.00
Year 15: 2025	$ 9,952,522.94	$ 6,617,162.73	$ 2,016,500.00
Year 16: 2026	$ 9,952,522.94	$ 6,617,162.73	$ 2,216,500.00
Year 17: 2027	$ 9,952,522.94	$ 6,617,162.73	$ 2,416,500.00
Year 18: 2028	$ 9,952,522.94	$ 6,617,162.73	$ 2,616,500.00
Year 19: 2029	$ 9,952,522.94	$ 6,617,162.73	$ 2,816,500.00
Year 20: 2030	$ 9,952,522.94	$ 6,617,162.73	$ 3,016,500.00
Year 21 - 99	0	0	$ 238,303,500.00
Categorial Totals:	$ 199,050,458.74	$ 132,343,254.50	$ 261,918,000.00
Sum:	**$ 593,311,713.24**		

Benefits

Health Benefits

I categorized benefit factors into health and economic benefits. Within health benefits, I identified 16 forms of health costs associated with consuming well water. This includes costs associated with cancers, preterm births, and waterborne infectious diseases. For most factors, I include calculations for both direct medical expenditures and indirect costs such as days off work or loss of life. However, the economic estimates for these costs vary across studies regarding the specific factors included in each cost category.

To estimate the health benefits, I quantify the negative impact of drinking water quality on health outcomes and translate it into economic costs for rural residences without access to a water system. When possible, I use statistics about water quality on the Crow Reservation. I rely most heavily on Eggers (2014), who details various chemical contaminate levels in wells across the reservation. In cases where data on water quality is unavailable, I refer to generalized studies on health risks associated with consuming well water or lack of access to potable running water in the US and Canada. I then locate studies that estimate the average incidence rate of illnesses, relative risk given exposure levels, and the direct and indirect economic impact of corresponding illnesses. Equation (2) serves as a basis for calculating the annual cost of each health factor, although the calculation methods may vary depending on the specific factor. Refer to Table 2: Estimated Health Benefits Factors (undiscounted, 2022 dollars).

Equation (2): Health Benefits Basis Equation

$$\text{HFAB} = \text{EP} \times \text{IR} \times (\text{RR}-1) \times (\text{COI} \times (\text{CPI-U2022} / \text{CPI-UY}))$$

Where HFAB=Health Factors Annual Benefit, EP=Exposed Population, IR=Incident Rate, RR=Relative Risk, COI=Cost of Illness (direct or indirect), CPI-UY=CPI-U Value of COI Year, CPI-U2022=CPI-U Value for 2022.

For example, to calculate the direct cost of cryptosporidiosis cases in Row 8 of Table 2, I refer to a 2016 study by Murphy et al. (2016) that attributes 11,398 annual cryptosporidiosis cases to the private wells that 1.4 million people rely on in Canada. While not directly representative of the US, I assume this study to be somewhat representative as Montana is geographically close to Canada. I calculate the estimated infections on the reservation annually attributable to well water by multiplying the 2,812 residents that consume their well water by the ratio (11398/1400000) of cryptosporidiosis cases developed in Canada (Bartlett & West Engineering et al., 2015; M. J. Eggers, 2014; Murphy et al., 2016). Based on these calculations, I attribute 22.89 cases of cryptosporidiosis on the Crow Reservation annually to private well access, as shown in the Est'd. Cases /Yr. (Crow) column.

To calculate the economic costs of these cases, I rely on a study from Collier et al. (2021) that estimates the direct medical costs of these cases to be an average of $59.76. I index this value from 2014, the year Collier indexes all monetary values, to 2022, using the CPI-U. This equates to the $72.56 in 2022 dollars shown in the Impact per Affected Person column. I then multiply this cost by the estimated number of cases attributable to private well access (Est'd. Cases /Yr. (Crow) column) to estimate that cryptosporidiosis cases have an annual direct cost of $1,661.17 on the reservation annually. I consider the economic cost of indirect expenses (i.e., lost time from work) using the same estimated number of cases but rely on other studies to estimate costs. Refer to Appendix A for further detail on each health factor.

Table 2: Estimated Health Benefits Factors
(undiscounted, 2022 dollars)

	Impact per Affected Person	Est'd. Cases /Yr. (Crow)	Estimated Annual Benefit	Standard Deviation	Yr. Begin	Yr. End
ural Residence)						
Pre-Term Birth	$76,017.36	0.13	$9,596.66	2,399.17*	14	100
e-Term Birth	$76,017.36	0.30	$23,031.99	5,758.00*	14	100
xposure:	$158,098.68	0.13	$20,830.34	5,207.59*	14	100
Exposure:	$581,508.66	0.13	$76,616.86	19,154.22*	14	100
xposure: Thyroid	$47,366.47	0.05	$2,155.47	538.87*	14	100
Exposure: Thyroid	$1,005,047.21	0.05	$45,735.83	11,433.96*	14	100
Cases	$73.87	2.42	$179.10	44.77*	14	100
oridiosis Cases	$494.39	2.42	$1,198.58	299.64*	14	100

Economic Benefits

I further break down the economic benefits category into Community Economic Impacts and Household Water Savings. Within Community Economic Impacts, I include several factors for direct and indirect jobs created or maintained (“saved”) by constructing the MR&I system. I include an estimate of operational jobs the system will create and an estimate of short-term construction jobs construction. Within Household Water Savings, I estimate how much residents using a water softening system will save on reduced softener usage and estimate future savings for electricity, soaps, and appliances for households without softeners but are using hard water. Finally, I estimate savings for residents that rely on buying or hauling their water use. I breakdown all household water savings by region served, as each will have a different start date.

To estimate the potential economic benefits of the MR&I system on the reservation, I heavily rely on the environmental assessment conducted by the Reclamation, Bureau of Indian Affairs, and Crow Tribe Water Resources group. While the report outlines the expected economic benefits, it does not provide a quantitative analysis. Therefore, I align the benefits with existing research or statistics to estimate their economic impact. To determine household savings from reduced water hardness, I draw on research by Eggers (2014) and estimate the average costs of buying or hauling water for households that rely on it using data from AWWWA. I use Equation (3) as a basis to calculate the annual cost of each economic factor; however, the calculations I use are often more complex and vary from factor to factor. See Table 3: Estimated Economic Benefits Factors (undiscounted, 2022 dollars).

Equation (3): Economic Benefits Basis Equation

$$\text{EFAI} = \text{IP} \times \text{EBPP} \times (\text{CPI-U2022} / \text{CPI-UY}))$$

Where EFAI= Economic Factors Annual Impact, IP=Impacted Population, EBPP=Economic Benefit Per Person, CPI-UY=CPI-U Value COI Year, CPI-U2022=CPI-U Value for 2022.

For example, an estimated 1,415 households on the Crow Reservation are unserved by water systems on the Crow Reservation and therefore rely on wells or other sources for their water. Six hundred sixty of these households are in the Bighorn Valley, 480 in the Little Bighorn Valley, and 275 in the Pryor service area (rows 32, 33 & 34) (US Bureau of Reclamation et al., 2016). Of these households, approximately 20%, or 283, do not consume this water, meaning they rely on buying or hauling water instead (see Impacted Population column) (M. Eggers et al., 2015). A recent study conducted by members of the Crow Nation interviewed tribal members that buy or haul their domestic water supply. Members interviewed spend an average of $264.49/month or $3,173.83 per year on hauling or buying water, shown in the Impact per Affected Person column. The study does not specify if these costs include transportation, time, or mental health costs associated with hauling water (Martin et al., 2021).

In calculating the average savings for tribal members that currently buy or haul water, I refer to the Bureau of Reclamation’s estimate that the monthly cost of water service will range from $9.42 to $32.09 (indexed from 2016 to 2021 with CPI-U) depending on location and household income (US Bureau of Labor Statistics, 2023; US Bureau of Reclamation et al., 2016). As I do not have numbers for an average monthly expense, I estimate households will pay $20.76 per month on average or $240 a year. Therefore, the average household will save $3,158.82 (column 3), adjusted for inflation with the CPI-U from 2021 to 2022 (US Bureau of Labor Statistics, 2023). Refer to Appendix B for further detail on each economic factor.

Table 3: Estimated Economic Benefits Factors
(undiscounted, 2022 dollars)

Impact per Affected Person	Impacted Population	Estimated Annual Benefit	Standard Deviation	Yr. Begin	Yr. End
$51,552.59	28.00	$1,443,472.59	360,868.15*	10	100
$49,987.10	82.84	$4,140,853.30	1,035,213.33*	5	20
$29,862.88	96.69	$2,887,465.13	721,866.28*	0	100
$29,862.88	18.93	$565,270.95	141,317.74*	0	100
$29,862.88	127.52	$3,808,227.85	952,056.96*	13	100
$29,862.88	44.51	$1,329,150.62	332,287.65*	13	100
$8.16	125.44	$1,024.21	$514.17	6	100

Population

As Reclamation projects the population on the Crow Reservation to grow throughout the next 50 years, I scale all benefit estimates to a 2010 population baseline and adjust for population growth for each year (US Bureau of Reclamation et al., 2016). As of 2010, the Crow Reservation had an estimated population of 6,863, including tribal and non-tribal members. The population is projected to grow to 9,050 by 2050 (Bartlett & West Engineering et al., 2015). To account for this, I created an equation that estimates population growth annually using a compounding growth model. I assume the population will continue to grow at the same compounding rate until 2110 and will distribute proportionally to how it is today. Based on this model, I estimate the Crow Reservation will have a population of 11,868 in 2110. As of the 2017-2021 American Community Survey (ACS), the Crow population slightly exceeds these estimates, as the ACS estimated population is 7,351, while my projection estimates the 2021 population to be 7,253. However, my projection is within one standard deviation of the ACS estimate (US Census Bureau, n.d.). Refer to Appendix A and Appendix B for further details on each factor's impacted populations.

I adjust for projected population growth and discount rates together for all factors, as represented in Equation (4).

Equation (4): Discount and Projected Population Equation

$$ATAB= (1/((1+r)^{Y})) \times (\Sigma HFAB+\Sigma EFAB) \times ((1+((9050/6863)^{(1/50)} - 1))^{Y})$$

Where ATAB=Adjusted Total Annual Benefit, r=Discount Rate, Y=Year of Benefit Calculation, ΣHFAB=Summation of all Health Factors Annual Benefit, ΣEFAB=Summation of all Economic Factors Annual Benefits.

National Implications

I conduct the benefit-cost analysis based on regional benefits as this best speaks to how the Crow Nation will benefit from the MR&I system. However, as job opportunities and other economic benefits have national implications, I also estimate benefits and the benefits-cost ratio from a national standpoint from two perspectives. In the first perspective, I assume that there are no national benefits to job creation on the Crow reservation, as if jobs are not created on the reservation, they may be created elsewhere.

In the second perspective, I consider how partially alleviating underemployment on the Crow Reservation may create economic opportunities for tribal members that would otherwise not move off the reservation for employment opportunities. This would therefore create jobs on a national scale. While many reservations, including the Crow Reservation, often have fewer economic opportunities for tribal members than off-reservation economies, tribal members still often choose to live on reservations despite these challenges. While every member that chooses to do so will have a different reason for staying on a reservation, cultural, spiritual, and familial ties play an important role. Furthermore, tribes have the right to self-govern on reservations, where they do not on off-reservation lands (Mika, 2023).

Ultimately many tribal members that reside on reservations face underemployment but will not move off the reservation to seek employment. From this perspective, I estimate how many jobs the Crow Reservation may gain if the MR&I system helps elevate the Crow Reservations civilian employment-population ratio to the national average. The 2013-2017

American Community Survey estimates the Civilian employment-population ratio on the Crow Reservation to be 48.6 percent and the national ratio to be 59.1 percent (Federal Reserve Bank of Minneapolis, n.d.). Approximately 66 percent of residents on the Crow Reservation are over the age of 16 or of working age (U.S. Census Bureau, 2021). Based on these statistics and the reservation's population of 6,863 in 2010, roughly 471 jobs would need to be created for the Crow Reservation to realize an equal civilian employment-population ratio. Since this is over the number of jobs I estimate in benefits, I assume from this perspective the national benefit may be equivalent to the regional benefit.

Standard Deviations

I assign standard deviations to each value to use in the uncertainty analysis. Where possible, I pull standard deviations from studies I rely on to estimate the population impacted by the benefits. However, as many of the studies I pull from do not provide a standard deviation or confidence interval, I estimate the standard deviation to be 25% above and below the mean value in these cases.

Uncertainty Analysis

As there is a level of uncertainty among all the benefits estimates, I run an uncertainty analysis on each benefit factor for the baseline scenario. I do not include costs in the analysis as the cost factors are much more uncertain. Using each benefit factor's mean and standard deviation, I simulate 200 scenarios with a normal distribution. I then create a 95 percent confidence interval based on the 95 percent range of scenarios[2].

There are two significant limitations of sensitivity analysis. Most importantly, many benefit factors do not have reported standard deviations or confidence intervals, so I assign a

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[2] Studies on the costs of birth and cancer-caused by excess nitrate exposure included standard deviations or confidence intervals. However, as the distribution was non-normal, I did not have time to successfully figure out a way to incorporate these into the normal distribution analysis.

standard deviation of 25 percent above and below the estimated annual benefits. Due to the variability in healthcare and economic development, these estimates are too conservative. The second limitation is in generating numbers randomly for each factor; I assume all factors are fully independent. This is not true, particularly within subsets of health and economic factors.

Assumptions

In calculating each estimated annual impact for benefit factors, I make many assumptions, nearly all of which are over-generalizations. Beyond assumptions I made in projecting population growth, I consistently assume that all conditions detailed in sources would hold true for the next 100 years if the MR&I system were not constructed. I also assume that the MR&I system will always meet all goals Reclamation designed it to, including meeting primary drinking water standards. Furthermore, I assume that high-risk individuals, such as pregnant women, are as likely to consume contaminated water as the general population, and those with the highest levels of contamination are not more or less likely to buy water or use water-softening systems. I also assume that statistics collected on subsets of the population on the reservation are fully representative of the reservation. Refer to Appendix A and Appendix B for assumptions I make about each factor.

Most likely, the most inaccurate assumption I make is that the health risk and cost data I collect from studies conducted in the US or Canada accurately apply to the Crow Reservation. However, this likely does not hold true as most residents on the reservation are members of the Crow Nation, and therefore they likely rely on Indian Health Services (IHS) for healthcare. The IHS's per capita spending is less than half of those of other federally funded healthcare programs, and therefore it is likely that upfront healthcare costs are initially less than average (US Government Accountability Office, 2018). However, untreated or undertreated illnesses often lead to higher direct and indirect costs in the long run (US Government Accountability Office, 2019).

Unquantifiable and Highly Uncertain Factors

In calculating benefits, I attempt to include as many regional factors as possible. However, due to the nature of this project, I did not include many unquantifiable or highly uncertain factors. I consider the quality of life, spiritual and cultural factors unquantifiable as I found no tangible way to translate these factors into monetary values. As the research I conduct is limited to existing literature and reports on the MR&I system, I exclude many more factors due to high uncertainty. Consequently, I do not have a perfect understanding of all the problems with the existing water infrastructure on the reservation and how the MR&I system will address those problems. For example, the environmental assessment details that many of the existing rural water systems on the reservation have violated the EPA's lead and copper rule in recent years (US Bureau of Reclamation et al., 2016). However, as reports detailing the extent of these violations are not public records, I am uncertain about the impact these violations have and to what extent the MR&I system will resolve such violations.

Furthermore, where I have information about how the MR&I system will improve existing conditions, there is a lack of literature or conflicting literature that prevents me from accurately quantifying the monetary cost of a given factor. For example, no research exists about how unsafe, inconvenient, or inconsistent water access impacts individual mental health in the US or similarly economically positioned countries. Moreover, there are conflicting studies about if regularly consuming water with high nitrogen content increases the risk of ovarian, liver, or bladder cancer; therefore, I do not factor in the cost of potentially elevated cancer risk (Temkin et al., 2019; Ward et al., 2018).

Ultimately, an entirely accurate benefit-cost analysis would include all potential factors. While mine does not, and this inherently makes for a flawed analysis, given the constraints of existing research and the scale of this analysis, I determine that it is most appropriate to exclude unquantifiable and highly uncertain factors entirely. I do this while recognizing that I underestimate factors and that the true economic benefit of the MR&I system is likely much higher. Ultimately, a more in-depth analysis would be necessary to estimate many factors more accurately, I excuse from the analysis. However, high-level benefit-cost analyses on environmental and health factors routinely exclude unquantifiable or uncertain factors (US Environmental Protection Agency, 2010).

Accelerated Construction Counterfactual Scenario

As stakeholders negotiate the timeline for funding distribution and, therefore, implicitly negotiate the fastest timelines for construction, I run a counterfactual scenario where I accelerate investment and construction by 25 percent. In the original scenario, investment and construction both end in 2030, 20 years after the date of enactment. In the accelerated counterfactual scenario, investment and construction end five years earlier in 2025, and all subsequent projects finish 25% sooner than their original date. The significant limitations in the counterfactual scenario are funding redistribution and an inexact timeline.

Concerning funding, I distributed all funding allocated in the last five years evenly across years 2 through 15. I also advance OM&R funding allocations from year 8 to year 6 and deflate inflation adjustments by averaging inflation adjustments made for 11 years between the Settlement Act and the transfer to the Crow Nation. Funding would likely be distributed a bit differently. Concerning the timeline, due to the model's limitations, I can only assign whole integers as dates benefits begin. I multiply the original start dates by 25% and round them to the nearest whole number. I adjust end dates, where applicable, differently depending on the factor. For some, I accelerate by 25 percent, while for others, I maintain the same number of years that benefits apply.

Reverse Osmosis System Counterfactual Scenario

As a secondary counterfactual scenario, I estimated the benefits and costs of the Crow Nation installing reverse osmosis systems (ROS) in all homes, businesses, and public services, such as schools, on the reservation to ensure safe water access for all residence with access to running water. This alternative scenario would address nearly all health concerns with the existing system as ROS effectively filters out nearly all known water contaminates in water sources of the reservation that pose health risks (Center for Disease Control and Prevention, 2023). Benefits would also start in year two, as opposed to taking up to 19 years to begin, as installation time would be much shorter than construction. However, this alternative would not address the capacity issues with the current system (US Bureau of Reclamation et al., 2016).

Benefits

To calculate the benefits of the secondary counterfactual scenario, I modified the benefits estimated in the baseline and primary counterfactual scenarios. Nearly all health benefits remain the same, as ROS effectively filter viruses, bacteria, and inorganic contaminates such as chemicals (Center for Disease Control and Prevention, 2023). However, roughly 7 percent of residents that currently buy or haul all their water have no access to running water (Martin et al., 2021). They would, therefore, not benefit from the installation of ROSs. I adjust the population that will benefit from a reduction in 'Type 2 Diabetes Attributable to a Lack of Running Potable Water Access' and 'Buying or Hauling Water (all regions)' accordingly.

More consequentially, I remove virtually all community-based economic benefits as installing ROSs on the existing water supply would not address the current system's critical access and safety issues. Currently, communities on existing systems face inadequate water storage and outages during peak use. Reclamation identifies these inadequacies as a significant limitation for further economic development opportunities on the reservation (US Bureau of Reclamation et al., 2016). Therefore, it is unlikely that ensuring clean water on the reservation without addressing capacity issues would spur economic development. I keep five operations jobs to account for plumbers employed by installing and maintaining the systems. Lastly, I keep all household economic benefits, except for the adjustment to the population that benefits from no longer needing to buy or haul water.

Costs

To estimate the costs of ensuring clean water through the reservation, I estimate the installation, maintenance, and operational costs of operating ROSs in all households, businesses, and public services. I calculate costs in a back-of-the-envelope style as the costs of ROSs vary widely. The program's true cost may be considerably higher or lower depending on the systems installed and true maintenance costs.

In estimating costs, I assume the number of households that will require ROSs to be the 2010 population of the reservation of 6,863 divided by the average household size of 4.4 residence (Bartlett & West Engineering et al., 2015; U.S. Census Bureau, 2021). As there is not much data on the number of businesses or public services on the Crow Reservation, I estimate that non-residential operations will require half the investment in installing and maintaining ROSs as houses. While there are likely much fewer non-residential operations, larger buildings, such as schools, will require more extensive and expensive systems. Refer to Table 4.

Installation Costs

As ROSs typically only last up to 15 years, I estimate installation costs will occur once every 15 years (Uta, 2023). I also include interim installation costs for population growth each year.

Maintenance Costs

ROSs require at least annual maintenance to ensure they work correctly and extend their use to 15 years. These costs include filter and membrane replacement, servicing, and water softener resin replacement. Although these systems do not require all these services annually, I average the costs across years to get a flat rate adjusted for population growth.

Operation Costs

ROSs require softening salt to operate. To account for the approximate amount of softening salt required to operate these systems, I use domestic and public supply use estimates in Big Horn County in 2015, as reported by the US Geological Survey (US Geological Survey, 2018). While the county does not perfectly overlap with the reservation and includes the city of Hardin, this is the most localized data available. I assume residence on and off the reservation in Big Horn County use the same amount of domestic and public supply water. Furthermore, I assume households will filter 50 percent of their water use as estimated by Pajl and DeBoer (2013) and estimate businesses and public services will filter 20 percent of their water use. Furthermore, I account for the current water hardness in each region of the reservation and estimate the amount of water-softening salt required to filter water accordingly. Refer to Appendix C for more information on cost calculations.

Table 4: Undiscounted Secondary Counterfactual Scenario Costs

Year	Installation	Maintenance	Operation
Year 0: 2010	$ -	$ -	$ -
Year 1: 2011	$ 2,352,638.90	$ -	$ -
Year 2: 2012	$ 13,051.81	$ 544,108.86	$ 172,377.81
Year 3: 2013	$ 13,197.03	$ 547,127.43	$ 173,334.12
Year 4: 2014	$ 13,270.25	$ 550,162.75	$ 174,295.73
Year 5: 2015	$ 13,343.87	$ 553,214.91	$ 175,262.68
Year 6: 2016	$ 13,417.89	$ 556,284.00	$ 176,234.99
Year 7: 2017	$ 13,492.33	$ 559,370.11	$ 177,212.69
Year 8: 2018	$ 13,567.18	$ 562,473.35	$ 178,195.82
Year 9: 2019	$ 13,642.45	$ 565,593.80	$ 179,184.40
Year 10: 2020	$ 13,718.14	$ 568,731.57	$ 180,178.47
Year 11: 2021	$ 13,794.24	$ 571,886.74	$ 181,178.05
Year 12: 2022	$ 13,870.77	$ 575,059.41	$ 182,183.18
Year 13: 2023	$ 13,947.72	$ 578,249.69	$ 183,193.89
Year 14: 2024	$ 14,025.10	$ 581,457.67	$ 184,210.20
Year 15: 2025	$ 14,102.90	$ 584,683.44	$ 185,232.15
Year 16: 2026	$ 2,556,204.81	$ 587,927.11	$ 186,259.76
Year 17: 2027	$ 14,259.82	$ 591,188.77	$ 187,293.08
Year 18: 2028	$ 14,338.93	$ 594,468.53	$ 188,332.14
Year 19: 2029	$ 14,418.48	$ 597,766.48	$ 189,376.95
Year 20: 2030	$ 14,498.47	$ 601,082.73	$ 190,427.57
Year 21 - 99	$ 17,856,093.82	$ 59,719,973.97	$ 18,919,740.48
Categorial Totals:	$ 23,012,894.89	$ 70,590,811.31	$ 22,363,704.16
Total Cost:	**$115,967,410.37**		

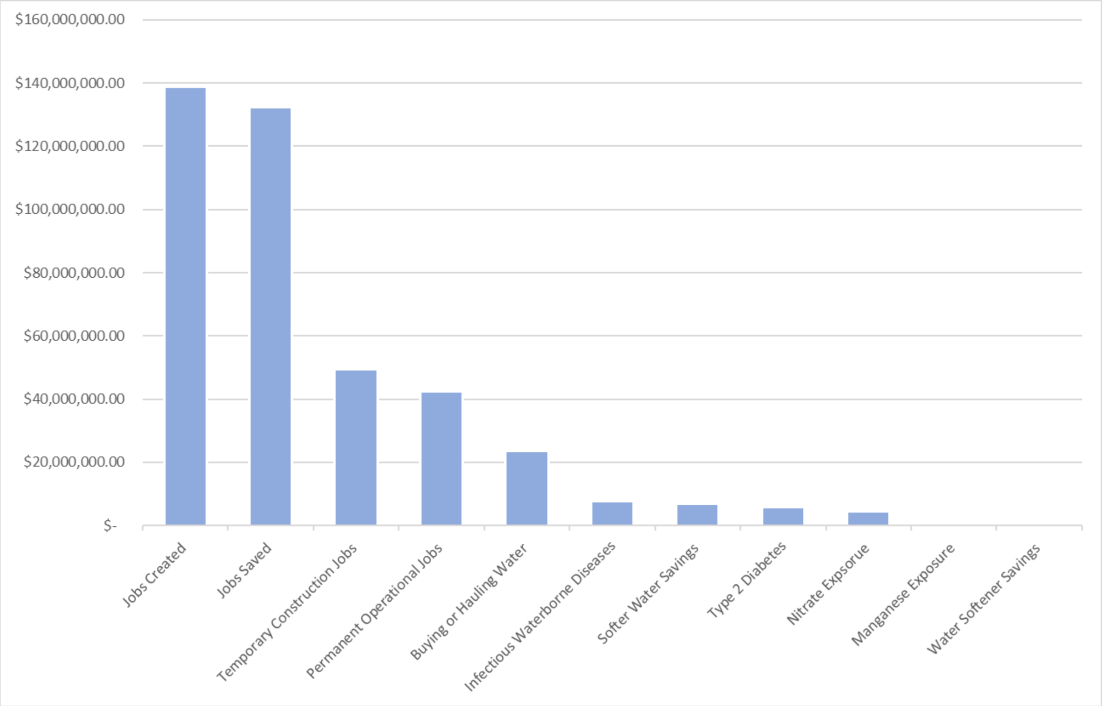
Results

Baseline Scenario

In the baseline scenario, quantifiable regional benefits 100 years out from the enactment of the Crow Tribe Water Rights Settlement Act range from a low of $115 million to a high of $1,776 million in 2022 dollars. The primary discrepancy in values arises from the difference in the discount rate, mainly because the measured timeframe is 100 years. Benefits accumulate to $413 million (95% CI $339 million - $508 million) at a 3 percent discount rate, $1,464 (95% CI $1,261 million - $1,776 million) at a 0.1 percent discount rate and $153 million (95% CI $115 million - $194 million) at a 7 percent discount rate. Costs accumulate to $320 million at a 3 percent discount rate, $632 million at a 0.1 percent discount rate, and $196 million at a 7 percent discount rate. The respective benefit-cost ratio for each discount rate is 1.29, 2.31, and 0.78.

Community economic impacts make up the most significant portion of benefits. At a 3 percent discount rate, jobs created, and jobs saved (direct and indirect) each account for over $130 million in present value. These two factors account for well over half of the economic benefits of the MR&I system. Construction and operational jobs comprise the next two largest sections of benefits, each accounting for over $40 million in present value. Savings families realize from no longer needing to buy or haul water make up the most significant household water benefits at nearly $24 million in present value. This benefit will be particularly substantial to just over 10 percent of reservation households routinely buying or hauling their water. Finally, health savings and other household water savings all amount to present values of less than $7 million—reference Figure 2.

Figure 2: Benefit Factors by Present Value at 3 Percent Discount Rate



National Interpretation

From the first national perspective, I assume the MR&I system will not generate any employment opportunities on a national scale. I remove all community economic benefits, including jobs created, jobs saved (direct and indirect), temporary construction, and permanent operational jobs. From this perspective, benefits amount to $50 million at a 3 percent discount rate, $211 million at a 0.1 percent discount rate, and $14 million at a 7 percent discount rate. All cost factors remain the same. The respective benefit-cost ratio for each discount rate is 0.16, 0.33, and 0.07.

In the second national perspective, I assume that constructing the MR&I system would provide employment opportunities for individuals who would otherwise not seek employment. All temporary and permanent jobs I account for in benefits total a bit under 400 jobs. As the Crow Reservation would need to see 471 additional jobs to match the national average civilian employment-population ratio, constructing the MR&I system may create employment opportunities for 400 individuals that would otherwise not have employment opportunities. Therefore, there is no change between this and the baseline regional scenario.

Accelerated Timeline Counterfactual Scenario

In the primary counterfactual scenario, with a 25 percent accelerated timeline, quantifiable regional benefits 100 years out from the enactment of the Crow Tribe Water Rights Settlement Act of 2010 accumulate to $419 million at a 3 percent discount rate, $1,466 million at a 0.1 percent discount rate, and $160 million. Costs accumulate to $334 million at a 3 percent discount rate, $689 million at a 5% discount rate, and $283 million at a 7 percent discount rate. The respective benefit-cost ratio for each discount rate is 1.29, 2.31, and 0.78.

Overall, with an accelerated timeline, the Crow Reservation would realize roughly an additional $22.1 - $23.2 million, depending on the discount rate. Depending on the discount rate, costs would also increase between $8.6 and $14.3 million. Overall accelerated construction and fund allocation by five years would create some short-term economic benefits but would increase costs more substantially and ultimately decrease the benefits-to-cost ratio.

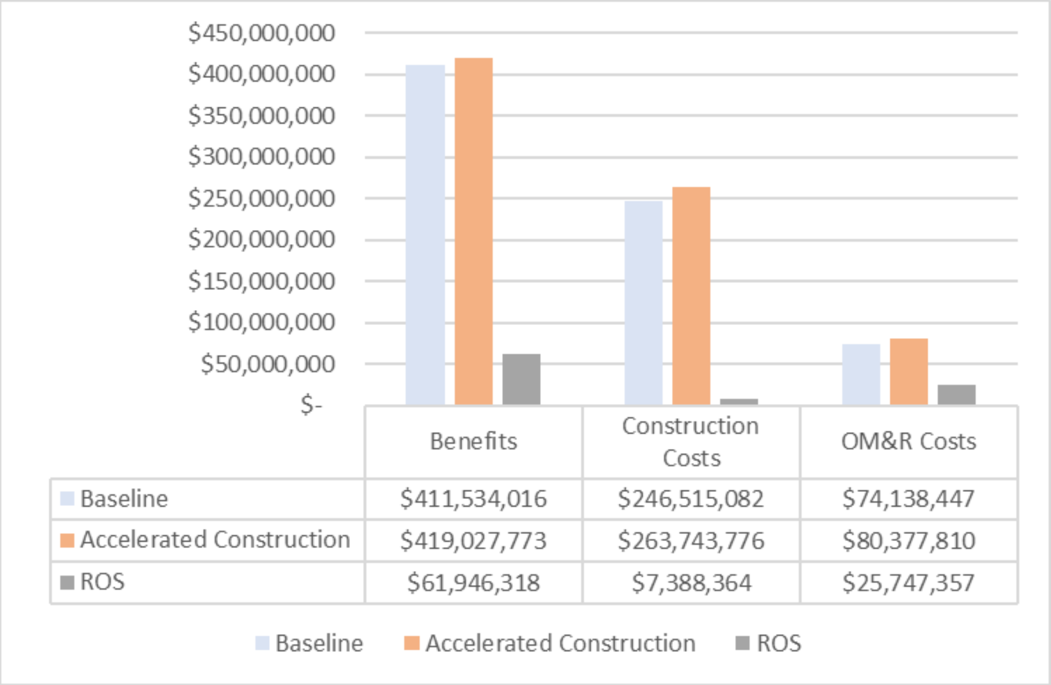
Reverse Osmosis System Counterfactual Scenario

In the reverse osmosis system counterfactual scenario, the present value of quantifiable regional benefits 100 years out from the enactment of the Crow Tribe Water Rights Settlement Act of 2010 accumulate to $62 million at a 3 percent discount rate, $212 million at a 0.1 percent discount rate, and $25 million at a 7 percent discount rate. Costs have a present value of $33 million at a 3 percent discount rate, $92 million at a 0.1 percent discount rate, and $14 million at a 7 percent discount rate. The respective benefit-cost ratio for each discount rate is 1.87, 2.31, and 1.78.

Scenario Comparison

Each scenario has different present value benefits and costs. The baseline and accelerated construction counterfactual scenarios are relatively close as they include all the same benefits and costs. The accelerated construction counterfactual scenario has a slightly higher present value for benefits and costs as with a faster construction timeline, construction costs are discounted less, and OM&R costs and benefits begin sooner. Lastly, all costs and benefits for the ROS counterfactual scenario are much lower as installing and operating these systems come at a much lower cost but do not generate the same economic benefits as the MR&I system will—reference Figure 3.

Figure 3: Net Present Value of Benefits and Cost of Each Scenario at 3 Percent Discount Rate



	Benefits	Construction Costs	OM&R Costs
Baseline	$411,534,016	$246,515,082	$74,138,447
Accelerated Construction	$419,027,773	$263,743,776	$80,377,810
ROS	$61,946,318	$7,388,364	$25,747,357

Discussion and Conclusion

While this analysis undoubtedly excludes some costs and many benefits, the results can indicate some of the economic costs and benefits tribes may realize from vital water infrastructure systems. This analysis also contributes to the discussion about how water rights settlements do or do not provide substantial economic benefits to tribes. Furthermore, these results are a unique literature contribution as economists have not conducted any comprehensive benefit-cost analysis on rural water systems in the United States or similar economically positioned countries. However, this also means there are no studies to directly compare these results to[3].

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[3] The most closely related literature is a recent study published by the nonprofit Dig Deep finds that a lack of basic water and sanitation services costs the US economy over $8.58 billion a year. This study does not account for residents that rely on wells but still have running water and instead examines the estimated 2.2 million Americans that do not have access to running drinking water or flush toilets in their homes. The study also further qualifies that the researcher only accounted for quantifiable factors and likely underestimated the economic burden of a lack of water and sanitation services (McGraw et al., 2022). Based on cost per capita results, total benefits on the Crow Reservation account for about half of the Dig Deep study estimates, excluding short-term benefits such as initial

In interpreting the results, I rely most heavily on the 3 percent discount rate as this most accurately represents the social costs of money. Based on the results of this analysis, the MR&I system is economically efficient at a discount rate of 3 and 0.1 percent, as constructing the system will save the tribe money in a 100-year timeframe. At a 7 percent discount rate, the MR&I system is not economically efficient, with a 0.78 benefit-to-cost ratio. However, even at a 7 percent discount rate, benefits are not insignificant as the MR&I system provides an important opportunity for the Crow Reservation to develop equitable water access for all, or nearly all, residents on the reservation.

From the first national perspective, where I exclude all community-based economic benefits under the assumption that the investment would not add jobs to the national economy, the MR&I system is highly inefficient. Benefits only amount to 0.16 of the total cost in present value at a 3 percent discount rate. However, this does not indicate that constructing the MR&I system is not worth funding as it potentially creates hundreds of jobs for people that would otherwise remain unemployed on the reservation, as I discuss in the secondary national perspective. Furthermore, as the Crow Nation settled their water rights to ensure funding for this system, the job opportunities it provides directly to the reservation residents and Crow Nation members are important to Nation.

Each counterfactual scenario provides insight into the economic efficiencies of alternative scenarios. Under the accelerate construction counterfactual scenario, the benefits-to-cost ratio is slightly lower than the baseline scenario. These results indicate that the costs associated with 25 percent faster construction of the MR&I system do not outweigh the benefits

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economic investments and construction jobs. This is somewhat to be expected as most households on the reservation reportedly have potable running water in their households, although, for some, it is unsafe to consume based on the EPA's primary and secondary drinking water standards (US Bureau of Reclamation et al., 2016).

the Crow Reservation would realize. Under the reverse osmosis systems, where all houses, businesses, and public services have reverse osmosis systems installed, the benefit-to-cost ratio is notably higher than that of the baseline scenario. However, costs and benefits are much lower than in either scenario with the MR&I system. The systems would not expand water on the reservation and would therefore limit economic opportunities. Furthermore, ROSs are consistently costly to re-install and upkeep, may not be as reliable as reservation-wide water infrastructure systems, are do not fully address inequities in water access. Ultimately, ROSs are likely not an ideal long-term solution on a reservation-wide scale.

The ROS counter factual scenario does indicate that installing ROSs, particularly in areas with high levels of various water contaminates, is likely an economically efficient intermediate measure, as the Crow Nation or tribes that have not settled water rights wait for more robust infrastructure. Those on the Crow Reservation that do not have access to clean drinking water still have to wait for decades after lawmakers approved the Settlement to connect to the water system. As the extension portions of the project are last in the process, based on the hypothetical timeline, users in the Pryor region would wait 20 years for adequate water (Bartlett & West Engineering et al., 2015). However, this timeline will likely take longer as construction is behind schedule (US Bureau of Reclamation, 2021).

Ultimately, while the MR&I system should spur economic growth, it will still require other community investments to fully realize all potential job creation. Although the MR&I system will provide many economic opportunities, the economic benefits will not be enough to bolster the Crow Reservation’s economy to be fully competitive with off-reservation opportunities, particularly as the population grows. So, although this system is essential for economic growth on the reservation, Crow Nation Members will likely still lack essential services such as adequate health care, accessible educational opportunities, or adequate and affordable housing (US Commission on Civil Rights, 2018).

Sanchez et al. (2022) echo this sentiment, arguing that while essential for procedural justice, water settlements will likely not create substantial benefits for tribes unless other agricultural and economic investments accompany them. While largely unrelated to the MR&I system, they find that tribes typically devote only a small portion of their water entitlements to expanded agricultural production in the initial years after reaching a water settlement, missing out on up to $1.6 billion in annual revenue primarily through lost agricultural opportunities. However, the authors rely on satellite data to estimate how much tribes are expanding agricultural production post settlement. Relying on that methodology assumes satellite data can accurately distinguish the impact of post-settlement water usage on agricultural output. In the case of the Crow Nation, the Crow Irrigation Project prioritizes revitalizing an old irrigation system while the last two priorities of the project are to expand irrigation on lands not previously used for irrigated agriculture (US Bureau of Reclamation & Crow Tribe Water Resources, 2015). In the context of Sanchez et al. (2022), this may mean they may underestimate agricultural impacts on the Crow Reservation. It depends on whether their satellite data can distinguish between lands irrigated with the old, decrepit system and lands irrigated with the rehabilitated system. If not, their method would not pick up the impact (in terms of higher output per acre) of the rehabilitated system. (US Bureau of Reclamation & Crow Tribe Water Resources, 2015).

Furthermore, for the Crow Nation, general economic and health concerns are likely more significant than agricultural ones, as based on funding from the Settlement Act, agricultural benefits are secondary compared to the MR&I system. The Crow Tribe Water Rights Settlement Act of 2010 provides roughly half of the funding for the CIP system compared to the MR&I.

However, Sanchez et al. (2022) still estimate that the Crow Tribe will use roughly 50% - 100% of their allocated water rights in a counterfactual scenario removing all barriers, while they project many other tribes will use a far lesser percentage of their entitlement. For these tribes using the least amount of their allocated water rights, agriculture appears to be far less critical based on settlement funding. For example, The Chippewa Cree Tribe of Rocky Boy, Montana, would use under 20% of their established water entitlement in the highest-use counterfactual scenario of Sanchez et al. (2022). The Chippewa Cree Tribe of the Rocky Boy's Reservation, Indian Reserved Water Rights Settlement, and Water Supply Enhancement Act of 1999 authorizes funding for a tribal compact administration account, economic development account, future water supply facility account, and on-reservation water development (Chippewa Cree Tribe of the Rocky Boy’s Reservation Indian Reserved Water Rights Settlement and Water Supply Enhancement Act of 1999).

Likewise, the Soboba Band of Luiseño Indians uses less than 10% of their water rights entitlement under the highest counterfactual scenario in Sanchez et al. (2022). The Soboba of Luiseño Indians Settlement Act allocated a total of $21 million and 7,000 acre-feet annually for funding towards water and sewer development and groundwater restoration to enable residential and commercial development in the future (US Department of the Interior, 2011). So, while funding allocated in these settlements typically relates to water, many tribes are leveraging it for economic development opportunities the federal government should have already funded, based on the trust responsibility and just allocations among the US population. Furthermore, many Winters-eligible tribes have yet to initiate a settlement, while many other tribes are not Winters-eligible and therefore do not have the opportunity to leverage their water rights for funding (Sanchez et al., 2022b). Without other economic investment, funding critical infrastructure on reservations based only on water rights settlements creates a dangerous precedent as it excludes tribes that are unable or ineligible to settle.

Federal funding is making some progress as the Inflation Reduction Act (IRA) sets aside $720 million for clean energy and climate investment explicitly for tribes or tribes within other federal programs (The White House, 2023). Tribes are also eligible for various other programs funded by the act, such as the Environmental Justice Thriving Communities Technical Assistance Programs, which will fund projects and technical assistance programs up to $50 million; however, recipients must complete the project in three years (US Environmental Protection Agency, 2023). Ultimately, water rights settlement cases and discretionary funding such as the IRA are vital building blocks for indigenous nations but alone do not go far enough.

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Appendix A: Health Benefit Factors Explanations

Note: This appendix is intended for referencing specific factor calculations and is not to be read all the way through.

Note on population assumptions made through this appendix:

Of the 6,863 residents of the Crow Reservation in 2010, 3,163 were reliant on the existing rural water system, while the remaining 3,700 residents were unserved by the rural water system and therefore primarily relied on well water, buying, or hauling water (Bartlett & West Engineering et al., 2015; US Bureau of Reclamation et al., 2016). Of the 3,700 residents, roughly 80% rely on well water, while the remaining 20% buy or haul their water (M. Eggers et al., 2018). Furthermore, 4% of residents have water-softening systems in their homes, which likely mitigates health risks associated with drinking well water (M. J. Eggers, 2014). Therefore, assuming households have roughly the same number of people, 2,812 residences consume hard well water, 960 buy or haul water, and the remaining 148 use water softeners. This breaks down to 2,960 and 740 residents, respectively. In discussing my techniques for calculating populations, I reference these statistics; however, I have designed my model to reflect the projected growth as explained in the Population subsection of Methods. Lastly, all assumptions outlined in the Assumption subsection of Methods also apply. I note assumptions not discussed in these sections separately.

Direct Cost Manganese Exposure: Pre-Term Birth

A recent meta-analysis concluded that maternal exposure to manganese increased the likelihood of pre-term birth by a risk ratio of 1.23 (Wu et al., 2022). In 2021 in the US, 10.5% of births were premature (Center for Disease Control and Prevention, 2022). At a 23% increase, roughly 3% of the affected population can attribute a pre-term birth to manganese exposure. 30 out of 151 in-use wells tested in a 2014 dissertation on Crow found manganese concentrations above the EPA's health advisory level of 0.3 mg/L (M. J. Eggers, 2014). As wells contaminated with high levels of manganese were spread across the reservation, assuming this percentage holds, roughly 19.9% of the 2,812 residents who consume hard well water have exposure to high-risk manganese levels (Bartlett & West Engineering et al., 2015; M. Eggers et al., 2018; M. J. Eggers, 2014). As of 2021, there are an estimated 93 births on the reservation annually (U.S. Census Bureau, 2021). Scaled to the 2010 population, this would be 88 births annually. Considering the percentage of the population exposed to high manganese concentrations, roughly 0.13 preterm birth annually on the reservation can be accredited to manganese exposure in utero.

A 2020 study estimates that pre-term birth costs an average of $76,153, with a standard deviation of $169,931 in 2016 dollars (Beam et al., 2020). This is in comparison to the average cost of giving birth in the US of $13,811 (Melillo, 2020). The report does not specify an inflation index, but I assume it to be in 2016 dollars as that is the year the study examines. Therefore, I do not adjust for inflation. I calculate that, on average, pre-term births cost $62,342 more than an average birth. I multiply the economic cost by the total number of births impacted by excess manganese and adjust for inflation. I multiply my standard deviation by the same inflation rate and population, then add and subtract it from my estimated value to create high and low estimates. Lastly, I estimate benefits will begin by at least year 14 based on expected service completion dates (Bartlett & West Engineering et al., 2015; M. Eggers et al., 2015).

Direct Cost Nitrogen Exposure: Pre-Term Birth

A 2021 study assessing how exposure to elevated nitrogen in drinking water in California estimated that women exposed to drinking water with 5 - 10 mg/L of nitrogen while pregnant had a risk ratio of 1.47 for preterm birth compared to those exposed to <5 mg/L. Women who consumed tap water with > 10 mg/L had a risk ratio of 2.52 for preterm birth (Sherris et al., 2021). 10 of 151 home in-use wells tested in a 2014 dissertation on Crow had nitrogen concentrations between 4-10 mg/L. I assume at least 8 of these 10 have a concentration above 5 mg/L. Another 8 of the 151 tested well have a concentration of nitrogen above 10mg/L (M. J. Eggers, 2014). In 2021 in the US, 10.5% of births were premature (Center for Disease Control and Prevention, 2022). At 47% and 152% increased risk, respectively, 4.7% and 15.4% of mothers reliant on these wells experience preterm births from elevated nitrogen levels.

As of 2021, there are an estimated 93 births on the reservation annually (U.S. Census Bureau, 2021). Scaled to the 2010 population, this would be 88 births annually. I multiplied the 2,812 residents that consume hard well water by the 8/151 wells, each exposed to a given level of elevated nitrogen. I then factor in the elevated risk of preterm birth by multiplying the exposed population by the 10.5% likelihood of preterm birth multiplied by the risk ratio -1. I do this calculation twice with different risk ratios to account for the two different levels of nitrogen exposure. I then add these equations together to estimate that 0.31 births are annually attributable to high manganese exposure from drinking water.

A 2020 study estimates that pre-term birth costs an average of $76,153, with a standard deviation of $169,931 in 2016 dollars (Beam et al., 2020). This is compared to the US's average cost of giving birth of $13,811 (Melillo, 2020). The report does not specify an inflation index, but I assume it to be in 2016 dollars as that is the year the study examines. Therefore, I do not adjust for inflation. I calculate that, on average, pre-term births cost $62,342 more than an average birth. I multiply the economic cost by the total number of births impacted by excess nitrogen, adjust for inflation from 2016 to 2022 and estimate the average year effect to begin to be at least by year 14 (Bartlett & West Engineering et al., 2015; M. Eggers et al., 2015).

Direct Cost Nitrogen Exposure: Colorectal Cancer

Individuals that consume over 5mg/L of nitrogen in their drinking water for over five years have a 2.6 relative risk of developing thyroid cancer (M. H. Ward et al., 2010). 18 of 151 tested wells on the Crow reservation had nitrogen levels above 4mg/L. I assume 2 of the 10 wells between 4 and 10 mg/L have less than 5 mg/L; therefore, 16 wells have nitrogen levels above 5mg/L.

The American Cancer Society estimated that there would be 153,020 cases of colorectal cancer in 2023 (American Cancer Society, 2023b). The US Census Bureau estimated that there are 334,233,854 residents in the US, meaning there is a 0.000457823 likelihood of an individual developing colorectal cancer (US Census Bureau, 2022). I estimate the number of residents that develop colorectal cancer attributable to high nitrogen levels in drinking water by multiplying the 2,818 residents that consume hard well water by the 16/151 wells with over 5mg/L of nitrogen. I then factor in the elevated risk of colorectal cancer by multiplying the exposed population by the likelihood of developing colorectal cancer by the respective relative risk -1. Based on this math, I estimate that roughly 0.13 colorectal cancer cases annually are attributable to high nitrogen concentrations in drinking water.

The average lifetime medical cost of colorectal cancer is $127,890 in 2014 dollars (Temkin et al., 2019). The study does not specify an index rate, so I assume it is in 2009 dollars, as this is the last year of the study (Aschebrook-Kilfoy et al., 2013). In my table, I attribute the entire lifetime treatment cost of a cancer case to one year, multiplied by the average annual cases. I assume a standard deviation of 25% above and below the mean to create high and low bounds. I then adjust for inflation from 2009 to 2022 and estimate the average year effect to begin at least by year 14 for all estimations (Bartlett & West Engineering et al., 2015).

Indirect Cost Nitrogen Exposure: Colorectal Cancer

I use the same average annual number of colorectal cancer cases attributable to elevated nitrogen levels in wells that I calculate in Nitrogen Exposure: Colorectal Cancer (direct cost) of 0.129 cases annually. The average indirect cost per colorectal cancer case was $471,914 in 2014 dollars based on years lived with disability and years of life lost (Temkin et al., 2019). I again attribute a cancer case's entire lifetime treatment cost to one year, multiplied by an annual average case of 0.129. I then adjust for inflation from 2014 to 2022, estimate the average year effect to begin to be at least by year 14, and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015; Temkin et al., 2019).

Direct Cost Nitrogen Exposure: Thyroid Cancer

Individuals that consume over 5mg/L of nitrogen in their drinking water for over five years have a 2.6 relative risk of developing thyroid cancer. 18 of 151 tested wells on the Crow reservation had nitrogen levels above 4mg/L. I assume 2 of the 10 wells between 4 and 10 mg/L have less than 5 mg/L; therefore, 16 wells have nitrogen levels above 5mg/L.

The American Cancer Society estimated that there would be 43,720 cases of thyroid cancer in 2023 (American Cancer Society, 2023a). The US Census Bureau estimated that there are 334,233,854 residents in the US, meaning there is a 0.0001308 likelihood of an individual developing thyroid cancer (US Census Bureau, 2022). I estimate the number of residents that develop thyroid cancer attributable to high nitrogen levels in drinking water by multiplying the

2,818 residents that consume hard well water by the 16/151 wells with over 5mg/L of nitrogen. I then factor in the elevated risk of thyroid cancer by multiplying the exposed population by the likelihood of developing thyroid cancer by the respective relative risk -1. Based on this math, I estimate that roughly 0.05 thyroid cancer cases annually, or a bit under 1 case every 20 years, is attributable to high nitrogen concentrations in drinking water.

The average lifetime medical cost of thyroid cancer is $34,723. The study does not specify an index rate, so I assume it is in 2009 dollars, as this is the last year of the study (Aschebrook-Kilfoy et al., 2013). In my spreadsheet, I attribute the entire lifetime treatment cost of a cancer case to one year, multiplied by the average annual cases. I calculate a high and low estimate by dividing the difference between the mean relative risk (2.6) and 95% confidence interval high and low range by two to get a standard deviation. I use the same processes as I did in creating my primary estimate to estimate high and low values. I then adjust for inflation from 2009 to 2022 and estimate the average year effect to begin to be at least by year 14 for all estimations (Bartlett & West Engineering et al., 2015).

Indirect Cost Nitrogen Exposure: Thyroid Cancer

I use the same average annual number of thyroid cancer cases attributable to elevated nitrogen levels in wells that I calculate in Nitrogen Exposure: Thyroid Cancer (direct cost) of 0.064 cases annually. The indirect cost of thyroid cancer cases is, on average, $813,008 in 2014 dollars based on years lived with disability and years lost of life in 2014 dollars (Temkin et al., 2019). I again attribute the entire lifetime treatment cost of a cancer case to one year, multiplied by the annual average cases. I then adjust for inflation from 2014 to 2022, estimate the average year effect to begin to be at least by year 14, and calculate my high and low values using the same method as direct cost (Bartlett & West Engineering et al., 2015).

Direct Cost Giardiasis Cases

A 2016 study estimates that 1207 giardiasis cases can annually be attributed to private well access in Canada. This is out of 1.4 million people reliant on wells for their water access (Murphy et al., 2016). While not in the US, I assume this study to be somewhat representative as Montana is geographically close to Canada. I calculate the estimated infections on the reservation annually attributable to well water by multiplying the 2,812 residents that consume their well water by the 1207 giardiasis cases attributable to consuming well water by the 1.4 million Canadian residents that consume their well water (Bartlett & West Engineering et al., 2015; M. J. Eggers, 2014; Murphy et al., 2016).

A 2021 study estimating the direct cost of waterborne infectious diseases in the US estimates that the US annually has 415,000 giardia cases attributable to waterborne diseases, which cost the US $24.8 million in direct medical expenditures (Collier et al., 2021). I calculate the annual impact per person by dividing the annual healthcare cost in the US by the annual number of cases attributable to waterborne diseases. I then multiply this by the estimated number of affected residences and adjust for inflation from 2014, the year Collier indexed health care calculations, to 2022 (US Bureau of Labor Statistics, 2023). Lastly, I assume an average start date of year 14 and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015).

Indirect Cost Giardiasis Cases

I use the same average annual number of giardiasis cases attributable to consuming well water that I calculate in “Direct Cost Giardiasis Cases.” However, as evidence on the indirect economic cost of illness, particularly waterborne illnesses, is limited, my calculations are very generalized. I reference a 2005 study that estimates the economic cost of illnesses from recreation on coastal waters in California. This study notes that indirect cost in the form of lost income is the primary component in their model, as most illnesses do not require professional medical care. However, the study does not detail what percentage of their model they attribute to lost income and instead references a 2000 study that examines the economic cost of food-borne illnesses in New Zealand, where lost income represents 87.4% of costs and loss of life accounts for another 8.5% percent of costs. Direct cost accounts for only 4.1%. I total lost income and loss of life costs for a total of 95.9% of total cost and apply this to my model by multiplying the direct cost for giardiasis cases by 95.9% divided by 4.1%. I again estimate benefits begin in year 14 on average, index from 2014 to 2022, and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015; US Bureau of Labor Statistics, 2023).

Direct Cost Cryptosporidiosis Cases

A 2016 study estimates that 11,398 cryptosporidiosis cases can annually be attributed to private well access in Canada. This is out of 1.4 million people reliant on wells for their water access (Murphy et al., 2016). While not in the US, I assume this study to be somewhat representative as Montana is geographically close to Canada. I calculate the estimated infections on the reservation annually attributable to well water by multiplying the 2,812 residents that consume their well water by the 11,398 cryptosporidiosis cases attributable to consuming well water by the 1.4 million Canadian residents that consume their well water (Bartlett & West Engineering et al., 2015; M. J. Eggers, 2014; Murphy et al., 2016).

A 2021 study estimating the direct cost of waterborne infectious diseases in the US estimates that the US annually has 322,000 cryptosporidiosis cases attributable to waterborne diseases, which costs the US $18.9 million in direct medical expenditures (Collier et al., 2021). I calculate the annual impact per person by dividing the annual healthcare cost in the US by the annual number of cases attributable to waterborne diseases. I then multiply this by the estimated number of affected residences and adjust for inflation from 2014, the year Collier indexed health care calculations, to 2022 (US Bureau of Labor Statistics, 2023). Lastly, I assume an average start date of year 14 and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015).

Indirect Cost Cryptosporidiosis Cases

I use the same average annual number of cryptosporidiosis cases attributable to consuming well water that I calculate in "Direct Cost Cryptosporidiosis Cases." However, as evidence on the indirect economic cost of illness, particularly waterborne illnesses, is limited, my calculations are very generalized. I reference a 2005 study that estimates the economic cost of illnesses from recreation on coastal waters in California. This study notes that indirect cost in the form of lost income is the primary component in their model, as the majority of illnesses do not require professional medical care. However, the study does not detail what percentage of their model they attribute to lost income and instead references a 2000 study that examines the economic cost of food-borne illnesses in New Zealand, where lost income represents 87.4% of costs and loss of life accounts for another 8.5% percent of costs. Direct cost accounts for only 4.1%. I total lost income and loss of life costs for a total of 95.9% of total cost and apply this to my model by multiplying the direct cost for cryptosporidiosis cases by 95.9% divided by 4.1%. I again estimate benefits begin in year 14 on average, index from 2014 to 2022, and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015; US Bureau of Labor Statistics, 2023).

Direct Cost Campylobacteriosis Cases

A 2016 study estimates that 9,273 campylobacteriosis cases can annually be attributed to private well access in Canada. This is out of 1.4 million people reliant on wells for their water access (Murphy et al., 2016). While not in the US, I assume this study to be somewhat representative as Montana is geographically close to Canada. I calculate the estimated infections on the reservation annually attributable to well water by multiplying the 2,812 residents that consume their well water by the 9,273 campylobacteriosis cases attributable to consuming well water by the 1.4 million Canadian residents that consume their well water (Bartlett & West Engineering et al., 2015; M. J. Eggers, 2014; Murphy et al., 2016).

A 2021 study estimating the direct cost of waterborne infectious diseases in the US estimates that the US annually has 171,000 campylobacteriosis cases attributable to waterborne diseases, which cost the US $30.5 million in direct medical expenditures (Collier et al., 2021). I calculate the annual impact per person by dividing the annual healthcare costs in the US by the annual number of cases attributable to waterborne diseases. I then multiply this by the estimated number of affected residences and adjust for inflation from 2014, the year Collier indexed health care calculations, to 2022 (US Bureau of Labor Statistics, 2023). Lastly, I assume an average start date of year 14 and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015).

Indirect Cost Campylobacteriosis Cases

I use the same average annual number of campylobacteriosis cases attributable to consuming well water that I calculate in "Direct Cost Campylobacteriosis Cases." However, as evidence on the indirect economic cost of illness, particularly waterborne illnesses, is limited, my calculations are very generalized. I reference a 2005 study that estimates the economic cost of illnesses from recreation on coastal waters in California. This study notes that indirect cost in the form of lost income is the primary component in their model, as the majority of illnesses do not require professional medical care. However, the study does not detail what percentage of their model they attribute to lost income and instead references a 2,000 study that examines the economic cost of food-borne illnesses in New Zealand, where lost income represents 87.4% of costs and loss of life accounts for another 8.5% percent of costs. Direct cost accounts for only 4.1%. I total lost income and loss of life costs for a total of 95.9% of total cost and apply this to my model by multiplying the direct cost for campylobacteriosis cases by 95.9% divided by 4.1%. I again estimate benefits begin in year 14 on average, index from 2014 to 2022, and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015; US Bureau of Labor Statistics, 2023).

Direct Cost STEC (O157) Infections

A 2016 study estimates that 16,913 STEC (O157) infections can annually be attributed to private well access in Canada. This is out of 1.4 million people reliant on wells for their water access (Murphy et al., 2016). While not in the US, I assume this study to be somewhat representative as Montana is geographically close to Canada. I calculate the estimated infections on the reservation annually attributable to well water by multiplying the 2,812 residents that consume their well water by the 16,913 STEC (O157) infections attributable to consuming well water by the 1.4 million Canadian residents that consume their well water (Bartlett & West Engineering et al., 2015; M. J. Eggers, 2014; Murphy et al., 2016).

A 2021 study estimating the direct cost of waterborne infectious diseases in the US estimates that the US annually has 3,360 STEC (O157) infections attributable to waterborne diseases, which costs the US $2.68 million in direct medical expenditures (Collier et al., 2021). As there is an obvious discrepancy between these numbers, I instead default to the 3,360 cases as it seems more reliable given the annual number of cases in the US. I attribute half of these to the 43 million people reliant on well water. I calculate the annual impact per person by dividing the annual healthcare costs in the US by the annual number of cases attributable to waterborne diseases (Collier et al., 2021). I then multiply this by the estimated number of affected residences and adjust for inflation from 2014, the year Collier indexed health care calculations, to 2022 (US Bureau of Labor Statistics, 2023). Lastly, I assume an average start date of year 14 and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015).

Indirect Cost STEC (O157) Infections

I use the same average annual number of STEC (O157) infections attributable to consuming well water that I calculate in "Direct Cost STEC (O157) Infections." However, as evidence on the indirect economic cost of illness, particularly waterborne illnesses, is limited, my calculations are very generalized. I reference a 2005 study that estimates the economic cost of illnesses from recreation on coastal waters in California. This study notes that indirect cost in the form of lost income is the primary component in their model, as the majority of illnesses do not require professional medical care. However, the study does not detail what percentage of their model they attribute to lost income and instead references a 2000 study that examines the economic cost of food-borne illnesses in New Zealand, where lost income represents 87.4% of costs and loss of life accounts for another 8.5% percent of costs. Direct cost accounts for only 4.1%. I total lost income and loss of life costs for a total of 95.9% of total cost and apply this to my model by multiplying the direct cost for STEC (O157) infections by 95.9% divided by 4.1%. I again estimate benefits begin in year 14 on average, index from 2014 to 2022, and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015; US Bureau of Labor Statistics, 2023).

Direct Cost Norovirus Cases

A 2016 study estimates that 55,558 norovirus cases can annually be attributed to private well access in Canada. This is out of 1.4 million people reliant on wells for their water access (Murphy et al., 2016). While not in the US, I assume this study to be somewhat representative as Montana is geographically close to Canada. I calculate the estimated infections on the reservation annually attributable to well water by multiplying the 2,812 residents that consume their well water by the 55,558 norovirus cases attributable to consuming well water by the 1.4 million Canadian residents that consume their well water (Bartlett & West Engineering et al., 2015; M. J. Eggers, 2014; Murphy et al., 2016).

A 2021 study estimating the direct cost of waterborne infectious diseases in the US estimates that the US annually has 1,330,000 norovirus cases attributable to waterborne diseases, which costs the US $59.1 million in direct medical expenditures (Collier et al., 2021). I calculate the annual impact per person by dividing the annual healthcare costs in the US by the annual number of cases attributable to waterborne diseases. I then multiply this by the estimated number of affected residences and adjust for inflation from 2014, the year Collier indexed health care calculations, to 2022 (US Bureau of Labor Statistics, 2023). Lastly, I assume an average start date of year 14 and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015).

Indirect Cost Norovirus Cases

I use the same average annual number of norovirus cases attributable to consuming well water that I calculate in “Direct Cost Norovirus Cases.” However, as evidence on the indirect economic cost of illness, particularly waterborne illnesses, is limited, my calculations are very generalized. I reference a 2005 study that estimates the economic cost of illnesses from recreation on coastal waters in California. This study notes that indirect cost in the form of lost income is the primary component in their model, as the majority of illnesses do not require professional medical care. However, the study does not detail what percentage of their model they attribute to lost income and instead references a 2000 study that examines the economic cost of food-borne illnesses in New Zealand, where lost income represents 87.4% of costs and loss of life accounts for another 8.5% percent of costs. Direct cost accounts for only 4.1%. I total lost income and loss of life costs for a total of 95.9% of total cost and apply this to my model by multiplying the direct cost for norovirus cases by 95.9% divided by 4.1%. I again estimate benefits begin in year 14 on average, index from 2014 to 2022, and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015; US Bureau of Labor Statistics, 2023).

Type 2 Diabetes Attributable to a Lack of Running Potable Water Access

Of the estimated 3,700 residents that do not have access to rural water systems, approximately 20%, or 740, do not consume their water (Bartlett & West Engineering et al., 2015; M. Eggers et al., 2015). A recent report estimated that in a population that lacks access to running water, 2.6% of the population has type 2 diabetes as a result of lacking access to consumable running water (McGraw et al., 2022). Considering the 740 residents without access to running potable water in their homes, an estimated 19.24 people have type 2 diabetes attributable to a lack of access to running water.

A recent study indexed to 2017 estimates that treating type 2 diabetes spends approximately $16,750 on healthcare costs annually, of which $9,600 of that is attributable to diabetes (American Diabetes Association, 2018). Based on expected service completion dates, I estimate the average year effect to begin to be at least by year 14 (Bartlett & West Engineering et al., 2015; M. Eggers et al., 2015). I then adjust for inflation from 2017 to 2023 using CPI-U and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (US Bureau of Labor Statistics, 2023).

Appendix B: Economic Benefit Factors Explanations

Note: This appendix is intended for referencing specific factor calculations and not to be read all the way through.

Permanent Operational Jobs

The environmental assessment assumes the MR&I system will require up to 28 permanent full-time staff members, including administrators, water treatment plant operators, and rural distributors of Operation, maintenance, and repair (US Bureau of Reclamation et al. 2016). Assuming the MR&I system requires 28 full-time workers, the mean start date for workers after the construction of each of the 23 systems is complete would be in year 10 or 2022 (Bartlett & West Engineering et al., 2015). The Bureau of Labor Statistics estimates a mean salary of $47,420 for water and wastewater treatment plant and system operators in the east-central Montana non-metropolitan area (US Bureau of Labor Statistics, 2021b). I then adjusted for inflation from May 2021 to 2022 using CPI-U and assumed a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (US Bureau of Labor Statistics, 2023).

Construction Jobs (short term)

As construction labor accounts for roughly 20% of the water treatment plant and distribution construction projects, construction wage labor would account for $49,280,000 of the $331,268,264 MR&I system construction budget (Botkeeper, 2019; Qasim et al., 1992). Construction of the MR&I project will run for approximately 17 years, from years 3 through 19 or from 2015 through 2031 (Bartlett & West Engineering et al., 2015). I use these as my dates for benefits beginning to benefits ending. This is an average annual expenditure of $3,897,273 on labor costs assuming roughly equal expenditures annually. The Bureau of Labor Statistics estimates a mean salary of $45,980 for construction laborers in the east-central Montana non-metropolitan area (US Bureau of Labor Statistics, 2021a). Adjusted for inflation from May 2021 to 2022 using CPI-U, there is a budget to employ roughly 78 workers (US Bureau of Labor Statistics, 2023). I also assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds.

Direct Permanent Jobs Saved

In a study of 53 federally funded rural water/sewer projects, the construction of systems, on average, directly saved 189 jobs (Bagi, 2002). Although construction will take 19 years from the enactment of the settlement agreement, I assume these benefits will begin in year 0 as the guarantee of a water system will likely influence people's economic decisions and willingness to invest in the community (Bagi, 2002). With an average per capita income of $12,156 and a 48.6% employment rate, I assume the average salary for people on the Crow reservation is $25,012 (Federal Reserve Bank of Minneapolis, n.d.). Scaling the average community size of 13,415 to the 6,863 people that live on the Crow reservation and MR&I service area, Crow should realize 54.79% of this investment. Lastly, adjust for inflation from 2017 to 2022 and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (Bartlett & West Engineering et al., 2015; US Bureau of Labor Statistics, 2023).

Indirect Permanent Jobs Saved

Following the same methodology in estimating “Direct Permanent Jobs Saved,” I estimated indirect jobs created based on an average of 37 indirect jobs created in rural communities following the construction of federally funded rural water/sewer projects (Bagi, 2002). I use the same population adjustment, high and low estimate scale, per capita income, beginning year for benefits, and inflation adjustment (Bartlett & West Engineering et al., 2015; US Bureau of Labor Statistics, 2023; US Census Bureau, n.d.).

Direct Permanent Job Created

In a study of 53 federally funded rural water/sewer projects, the construction of systems, on average, directly created 304 jobs (Bagi, 2002). As construction takes 17 years to complete, I assume, on average, job benefits will begin when 75% of the system is complete or in year 13 (2023) (Bartlett & West Engineering et al., 2015). With an average per capita income of $12,156 and a 48.6% employment rate, I assume the average salary for people on the Crow reservation is $25,012. Scaling the average community size of 13,415 to the 6,863 people that live on the Crow reservation and MR&I service area, Crow should realize 54.79% of this investment. I also subtract the 28 permanent MR&I operation-based jobs that are already accounted for but exclude construction jobs as those are temporary. Lastly, I adjust for inflation from 2017 to 2022 and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (US Bureau of Labor Statistics, 2023).

Indirect Permanent Jobs Created

Following the same methodology in estimating “Direct Permanent Jobs Created,” I estimated indirect jobs created based on an average of 87 indirect jobs created in rural communities following the construction of federally funded rural water/sewer projects (Bagi, 2002). I use the same population adjustment, high and low bounds, per capita income, beginning year for benefits, and inflation adjustment (Bartlett & West Engineering et al., 2015; US Bureau of Labor Statistics, 2023; US Census Bureau, n.d.).

Direct Private Investment

In a study of 53 federally funded rural water/sewer projects, the construction of systems spurred an average of $10,514,100 in direct private investment in rural communities in the seven years after construction finished (Bagi, 2002). I account for 7 years of economic investment on the reservation by dividing this total by 7 years. Furthermore, although it is likely that investment will continue beyond this point, there is no research to support this. In estimating the year benefits benign, I assume benefits begin in year 12, when the majority of the project is completed and end in year 19, when the project is completed (Bartlett & West Engineering et al., 2015). Scaling the average community size of 13,415 to the 6,863 people that live on the Crow reservation and MR&I service area, Crow should realize 54.79% of this investment. (US Census Bureau, n.d.). I adjust for inflation from 1990 to 2022 CPI-U and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (US Bureau of Labor Statistics, 2023).

Indirect Private Investment

Following the same methodology in estimating "Direct Private Investment," I estimated indirect private investment based on an average of $1,459,560 indirect investment in rural communities following the construction of federally funded rural water/sewer projects (Bagi, 2002). I use the same population adjustment, high and low estimate scale, and inflation adjustment (Bartlett & West Engineering et al., 2015; US Bureau of Labor Statistics, 2021a; US Census Bureau, n.d.).

Direct Public Investment

In a study of 53 federally funded rural water/sewer projects, the construction of systems spurred an average of $1,332,917 direct public investment in rural communities in the seven years after construction finished (Bagi, 2002). I account for 7 years of economic investment on the reservation by dividing this total by 7 years. Furthermore, although it is likely that investment will continue beyond this point, there is no research to support this. In estimating the year benefits benign, I assume benefits begin in year 12, when the majority of the project is completed and end in year 19, when the project is completed (Bartlett & West Engineering et al., 2015). Scaling the average community size of 13,415 to the 6,863 people that live on the Crow reservation and MR&I service area, Crow should realize 54.79% of this investment. I adjust for inflation from 1990 to 2022 CPI-U and assume a standard deviation of 25% above and below my estimated annual cost to create high and low bounds (US Bureau of Labor Statistics, 2023).

Indirect Public Investment

Following the same methodology in estimating "Direct Public Investment," I estimated indirect private investment based on an average of $784,415 indirect investment in rural communities following the construction of federally funded rural water/sewer projects (Bagi, 2002). I use the same population adjustment, high and low estimate scale, and inflation adjustment (Bartlett & West Engineering et al., 2015; US Bureau of Labor Statistics, 2021a; US Census Bureau, n.d.).

Water Softener Savings: All Regions

Of 151 household well users surveyed, only 4% use reverse osmosis systems, or water softeners, on the Crow reservation; I assume this statistic holds true for all well water users (M. J. Eggers, 2014). I assume another 4% of users reliant on existing water systems also use reverse osmosis systems or another water softening system. While it may be less than this, it is a conservative estimate as softeners save money over time, lessening energy for water heating, lessening soaps and detergents appliances need for cleaning, and extending the lifetime of appliances (US Department of Energy, n.d.). Pajl & DeBoer (2013) estimate savings rural residents incur from reduced water softening after the development or improvement of rural water systems. Based on the hardness of the water in their study area, they estimate that residents reliant on groundwater saved on average $11.21 a year, and residents reliant on surface water saved an average of $13.61 a year in 2013. My estimates range from savings of $7.13 to $47.43 per person per year, as water hardness varies greatly among the reservation. In calculating these estimates, I rely on Pajl & DeBoer's (2013) equations for estimating savings in water softeners in transitioning to a rural water system:

Daily Softening salt reduction: (population x daily water demand x 0.5) x (water hardness before rural water system - rural water hardness) / 17) x (0.4/1000).

Annual Cost: (Daily softening salt reduction x 365 days) / population) x 1 pound of softening cost.

These equations assume households soften approximately 50% of their daily water use. I assume that Crow residents use the same amount of water as the average person in the US at 82 gallons per day at home, and the average water hardness after the MR&I system is complete will be 125mg/L based on the goal of 100-150mg/L (Bartlett & West Engineering et al., 2015; US Environmental Protection Agency, 2022). I also find that a 40-pound bag of softening salt currently costs $7.48, or ¢18.7 per pound. I then calculate the average water softening cost per water system based on the population served, the current average water hardness of that system, and the average year benefits will start for that population. I estimate unserved rural residences as I do not have exact populations for unserved rural water systems, so I divide the total number of unserved residences (3,700) by the total number of unserved households (1,415) to estimate 2.61 residences per household (Bartlett & West Engineering et al., 2015; US Bureau of Reclamation et al., 2016).

Currently Served Residence

- Average water hardness: 249 (estimated from 176-322 mg/L range, no CI). Assume SD to be 25% below and above the mean: 62.25.
- Population: 125.44 (3,163 x 0.04)
- Average Benefit Start Date: 7

Data from: (Bartlett & West Engineering et al., 2015; US Bureau of Reclamation et al., 2016)

Big Horn River Valley

- Average water hardness: 845.29 mg/L (CI for mean: 545.29 - 1146.45, SD: 150)
- Population: 69.03 (660 x 2.61 x 0.04)

- Average Benefit Start Data: 11

Little Big Horn River Valley

- Mean water hardness: 467.52 mg/L (CI for mean: 380.63 - 554.41, SD: 43.45)
- Population: 50.20 (480 x 2.61 x 0.04)
- Average Benefit Start Data: 13

Pryor

- Average water hardness: 233.26 mg/L (95% CI for mean:144.96 - 321.57, SD:44.15)
- Population: 28.76 (275 x 2.61 x 0.04)
- Average Benefit Start Data: 19

Data from: (Bartlett & West Engineering et al., 2015; M. J. Eggers, 2014; US Bureau of Reclamation et al., 2016)

Saving from Softer Water (electricity, soaps, and appliances): All Regions

Following the assumptions, I made in calculating Water Softening Savings, I assume that the new rural water system will reduce water hardness to an average of 125mg/L and that 96% of residents currently do not use any kind of water softeners in their homes (Bartlett & West Engineering et al., 2015; M. J. Eggers, 2014). For this section, I estimate annual residence savings from softer water in reduced energy costs of water heaters, savings on soaps and detergents, and reduced replacement costs of home appliances. I calculate energy and soap savings based on water hardness by region but generalize appliance replacements as there is no information about how varying degrees of hardness impact the lifespan of an appliance.

Appliances

Transitioning from hard water to soft water can double the lifespan of many appliances (Water Quality Research Foundation, 2009). However, after the MR&I system is complete, the projected water hardness will likely still, at least partially, deliver hard water, which is anything over 120 mg/L. Because of this, I do not calculate savings based on transitioning from hard to soft water, but instead, I estimate that appliances will extend their life expectancy by at least one-third of what they would be if water hardness remained the same. As households save an estimated $90 annually on appliance replacement, and there are roughly 2.5 people per household, I estimate savings to be about $12 per person annually (Homewater101, n.d.; Statistica, 2023). I use a standard deviation of 25% for my high and low estimates.

Soaps

Experts constantly recognize that softer water is better at cleaning, and therefore homes with softer water need to use fewer soap products. However, there needs to be more explicit research on how water hardness impacts laundry and dishwasher detergent use. Both can save about 7.5% per 5 grains is reduced (Water Quality Research Foundation, 2009). Using this information and the fact that the average household of 2.5 people spent $80.5 on laundry and dishwasher detergent in 2021, I can calculate an estimated reduction in spending on soaps and detergents on the reservation from the MR&I project. In making these calculations, I assume that the average American consumer has water hardness in the US is 100mg/L or 5.84 grains based on USGS data (USGS source). Given the population distribution, this is more likely a bit of an overestimate than an underestimate. Refer to Breakdown by Region for more information on calculations.

Soap Savings Per Person Calculation: (Annual household expenditures on soaps/people per household) * (percent extra savings per 5-grain reduction/5 grains) * predicted grain reduction.

Water heating savings

As of 2005, 65% of homes in the West relied on gas water heaters. Based on national statistics, I assume another 30% of households rely on electric heaters, while 5% rely on other methods or do not have a water heater. That 5% is not included in these calculations. Gas water heaters are 4% less efficient for every 5 grains in water, and I estimated that electric heaters become an average of 5% per 5 grains less efficient as they can become 48% less efficient with 25 grains of calcium built over time. On average, in Montana, a 3-person household spends an average of $308 a year or $102.66 a person. I estimate future savings with a hardness index of 125 mg/L based on mean hardness and the confidence intervals range.

Predicted grains reduction: (water hardness before rural water system / projected rural water hardness) / 17.1.

Water Heater Savings Energy Equation: (annual energy cost of running a water heater per person* gas heater inefficiencies per 5 grains*(predicted grain reduction/5 grains) *percent population that uses gas heater) + (annual energy cost of running a water heater per person* electric heater inefficiencies per 5 grains*(predicted grain reduction/5 grains) *percent population that uses electric heater)

Breakdown by Region

Currently Served Residence

- Average water hardness: 249 (estimated from 176-322 mg/L range, no CI, assuming SD to be 25% above and below mean: (186.75-311.25)
- Predicted grain reduction: 7.25 (Estimated Range: 3.61 - 10.89)
- Population: 3010.56 (3,163 x 0.96)
- Average Benefit Start Date: 7
- Water heating energy savings per person: (102.66*0.04*(7.25/5) *0.65) + (102.66*0.05*(7.25/5) *0.35)
- Soap savings per person: ((80.5/2.5) * (0.075/5) *7.25)

Data from (Bartlett & West Engineering et al., 2015; US Bureau of Reclamation et al., 2016)

Big Horn River Valley

- Average water hardness: 845.29 mg/L (CI for mean: 545.29 - 1146.45, SD: 150)
- Predicted grain reduction: 42.12 (1 SD: 33.35 - 50.89)
- Population: 1656.76 (660 x 2.61 x 0.96)
- Average Benefit Start Data: 11
- Water heating energy savings per person: (102.66*0.04*(42.12/5) *0.65) + (102.66*0.05*(42.12/5) *0.35)
- Soap savings per person: ((80.5/2.5) * (0.075/5) *42.12)

Little Big Horn River Valley

- Mean water hardness: 467.52 mg/L (CI for mean: 380.63 - 554.41, SD: 43.45)
- Predicted grain reduction: 20.03 (1 SD: 17.49 - 22.56)
- Population: 1204.92 (480 x 2.61 x 0.96)
- Average Benefit Start Data: 13
- Water heating energy savings per person: (102.66*0.04*(20.03/5) *0.65) +(102.66*0.05*(20.03/5) *0.35)
- Soap savings per person: ((80.5/2.5) * (0.075/5) *20.03)

Pryor

- Average water hardness: 233.26 mg/L (95% CI for mean:144.96 - 321.57, SD:44.15)
- Predicted grain reduction: 6.33 (1 SD: 3.75 - 8.91)
- Population: 690.32 (275 x 2.61 x 0.04)
- Average Benefit Start Data: 19
- Water heating energy savings per person: (102.66*0.04*(7.25/5) *0.65) + (102.66*0.05*(7.25/5) *0.35)
- Soap savings per person: ((80.5/2.5) * (0.075/5) *6.33)

Data from (Bartlett & West Engineering et al., 2015; M. J. Eggers, 2014; US Bureau of Reclamation et al., 2016)

Buying or Hauling Water: All Regions

An estimated 1,415 households on the Crow Reservation are unserved by water systems on the Crow Reservation and therefore rely on wells or other sources for their water. 660 of these households are in the Bighorn Valley, 480 in the Little Bighorn Valley, and 275 in the Pryor service area (US Bureau of Reclamation et al., 2016 (US Bureau of Reclamation et al., 2016). Of these households, approximately 20%, or 283, do not consume this water, meaning they rely on buying or hauling water instead (M. Eggers et al., 2015). A recent study estimated the hauling and purchasing cost for water per household per month on the Crow reservation estimated an average monthly cost of $264.49/month or $3,173.83 per year. The study does not specify if these costs include transportation, time, or mental health costs associated with hauling water (Martin et al., 2021).

The Bureau of Reclamation estimated the monthly cost for water service to range from $9.42 to $32.09 (indexed from 2016 to 2021 with CPI-U) depending on location and household income (US Bureau of Labor Statistics, 2023; US Bureau of Reclamation et al., 2016). As I do not have numbers for an average monthly expense, I estimate households will pay $20.76 per month on average or $240 a year. Therefore, the average household will save $3,158.82, adjusted for inflation with the CPI-U from 2021 to 2022 (US Bureau of Labor Statistics, 2023). Year benefits begin are based on extension year project priority outlines in the Crow MR&I project timing schedule; each service area has a different start date (Bartlett & West Engineering et al., 2015). I do not have a standard deviation value, so I assume it to be 25% above and below my estimate to create my high and low bounds.

Appendix C: Reverse Osmosis System Cost Calculations

Installation

Domestic Reverse Osmosis systems can cost between $150 to $7,500 to install, depending on the size and scale of the system, but the average cost is $1,000 (Crail & Saddler, 2022). With frequent maintenance, these systems can last from 10-15 years (Uta, 2023). I assume these systems have an average of 15 years and cost $1,000 to replace. I distribute these costs as an average across all years (i.e., 100/15 per household).

Maintenance

Data on the costs of maintenance of reserve osmosis systems vary greatly. Filter & membrane replacements can cost between $100-$400 annually, I assume an annual cost of $250. Water softener annual services reportedly cost between $100-$250. I assume an annual cost of $150. Water softener resin replacement, which needs to take place every 5 to ten years, can cost between $200-$400 (Noel, 2023). I assume an average cost of $300 every 7.5 years, distributed as an average across each year. In total, I assume an annual maintenance cost of $440 annually per household.

Operation

Softening salt is the last cost factor in owning and operating a reverse osmosis system. Pajl & DeBoer (2013) estimate savings rural residents incur from reduced water softening salt after the development or improvement of rural water systems. In calculating domestic savings estimates, I rely on Pajl & DeBoer's (2013) equations for estimating savings in water softeners in transitioning to a rural water system:

Daily Softening salt reduction: (population x daily water demand x 0.5) x ((water hardness before rural water system - rural water hardness) / 17) x (0.4/1000).

Annual Cost: (Daily softening salt reduction x 365 days) / population) x 1 pound of softening cost.

In calculating businesses and public services savings estimates, I modify Pajl & DeBoer's (2013) equations for estimating savings in water softeners in transitioning to a rural water system so that only 20%, compared to 50% of all water used is softened with the reverse osmosis system:

Daily Softening salt reduction: (population x daily water demand x 0.2) x ((water hardness before rural water system - rural water hardness) / 17) x (0.4/1000).

Annual Cost: (Daily softening salt reduction x 365 days) / population) x 1 pound of softening cost.

To calculate daily water use for each factor, I used domestic and public supply use estimates in Big Horn County in 2015, as reported by the US Geological Survey (US Geological

Survey, 2018). I assume residents on and off the reservation in Big Horn County use the same amount of domestic and public supply water. Furthermore, I assume the system will soften the water to an average of 125mg/L, the same average I project with the MR&I system, which aims for water hardness to range from 100-150mg/L (Bartlett & West Engineering,g et al., 2015; US Environmental Protection Agency, 2022). A 40-pound bag of softening salt costs $7.48, or ¢18.7 per pound. I then calculate the average water softening cost per water system based on the population served and that system's current average water hardness. I estimate unserved rural residences as I do not have exact populations for unserved rural water systems, so I divide the total number of unserved residences (3,700) by the total number of unserved households (1,415) to estimate 2.61 residences per household (Bartlett & West Engineering et al., 2015; US Bureau of Reclamation et al., 2016).

2015 Domestic supply Big Horn County: 1,140,000 / 13,310: 85.65 gallons per day per capita

Currently Served Residence

- Average water hardness: 249
- Population: 3,163

Data from: (Bartlett & West Engineering et al., 2015; US Bureau of Reclamation et al., 2016)

Big Horn River Valley

- Average water hardness: 845.29 mg/L
- Population: 1,726 (660*(3700/1415))

Little Big Horn River Valley

- Mean water hardness: 467.52 mg/L
- Population: 1,255 (480*(3700/1415))

Pryor

- Average water hardness: 233.26 mg/L (95% CI for mean:144.96 - 321.57, SD:44.15)
- Population: 719 (275*(3700/1415)

Data from: (Bartlett & West Engineering et al., 2015; M. J. Eggers, 2014; US Bureau of Reclamation et al., 2016)

2015 Total Withdrawn Public Supply: 1,210,000 / 13,310: 90.91 gallons per day per capita.

In estimating the cost of water softeners for the public supply of water, I continue to assume that businesses and public services will filter only 20 percent of all water used for public supply. I also assume that all businesses and public services rely on the existing water system and have an average water hardness of 249.