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ASSESSMENT OF COSTS OF CENTRALIZED AND DECENTRALIZED WATER SYSTEMS ON FIRST NATION COMMUNITIES

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Abstract: Water systems on First Nations fail to provide safe drinking water throughout Canada. Many of these communities have individual, household cisterns as part of a decentralized water system that are prone to contamination causing health issues. It has been suggested that there is insufficient funding provided by Indigenous and Northern Affairs Canada (INAC) for water infrastructure projects on First Nations which is preventing communities from addressing these issues that can be mitigated by moving to a safer, centralized distribution water system. Currently, the funding formula used by INAC focusses too simply on the construction costs of water infrastructure projects without providing any consideration for human health related costs. This research presents a proposed expansion to the funding formula to include the potential costs associated with health and social impacts that a decentralized distribution system has on a community. After creating an updated formula, a comparison study was performed on an example Saskatchewan First Nation where the capital cost of a centralized and decentralized system was compared using INAC's funding formula. Additional annual costs were added to an updated funding formula showing a 'true' cost of decentralized systems based on human health related costs. Taking these added costs into consideration, it was found that the less safe decentralized system actual cost was higher than the safer centralized system for this example community. Overall, the methods of funding allocations for communities in need of upgraded water systems must be expanded to reflect long term impacts as justification for greater capital investment.

1 BACKGROUND AND INTRODUCTION

1.1 Drinking Water in Indigenous Canada

Human health in First Nations communities has historically been negatively impacted by poor access to clean drinking water (Waldner et al. 2017). Although the issue has been recognized, communities still struggle for solutions to drinking water challenges that must address technical, social, and political aspects specific to each community. The responsibility for providing water infrastructure on First Nations is shared by Indigenous and Northern Affairs Canada (INAC), Health Canada (HC), and Environment Canada (EC) (Bradford et al. 2016). This structure of multiple overlapping Federal departments has historically complicated the implementation of water, and other infrastructure, projects on First Nations. In addition, these departments generally only provide 80% of water infrastructure costs with the nation's Chief and Council being responsible for covering the remaining 20% of the infrastructure costs (typically collected via user fees in non-First Nations communities) (Bradford et al. 2016). This lack of full funding is an ongoing issue since First Nations distribute water without charge to their communities given water is considered a human right and has a spiritual resource beyond its utility as a physical necessity.

Funding issues directly impact the quality of water treatment and distribution to the community leading to the creation of health challenges in First Nations that have existed for decades. In Canada, it is more likely for a First Nations community to experience waterborne illnesses and to have at risk water infrastructure as compared to the national average (Boyd 2006). Overall, there are 70 First Nations in Saskatchewan and 617 in Canada (Statistics Canada 2011). Saskatchewan is home to 11.7% of Canada's First Nations population making up 10.7% of the total provincial population (Statistics Canada 2011). Of these, 30% of water systems on First Nation communities are described as high risk (Black and McBean 2017) which is defined by Burnside (2011) as a water distribution system that has major deficiencies that could impact the health of a community. In Saskatchewan, 26% of First Nations have high risk water systems (Burnside 2011). There are a wide range of health issues that are prevalent on First Nations as a result of high risk water systems including gastrointestinal illnesses, skin disease, and kidney disease. Additionally, limited or restricted access to safe drinking water can also have an impact on mental health by causing anxiety and stress (Bradford et al. 2016). These health and social costs are not currently considered in the funding formula used to determine water infrastructure costs including the choice to install either centralized (piped-to-homes) versus decentralized (truck-to-cistern) systems. Generally, centralized water systems delivering water directly to household taps are less prone to producing human health issues versus decentralized systems that produce numerous potential contamination sources discussed in detail below.

1.2 Water Systems and Health

Despite technological advances that have led to improved drinking water treatment systems, there are still cases of failing Canadian water systems negatively impacting human health. Possibly the most prominent case in Canada's recent history was in 2000 with an *E. coli* outbreak in Walkerton, Ontario, where over 2,000 people were impacted by tainted water including 7 known fatalities (Lebel and Reed 2010). In Saskatchewan, the 2001 outbreak of gastroenteritis in North Battleford affected approximately 6000 people (Hrudey and Hrudey 2004). Given their populations, it is easy to track these large outbreaks in municipal supplies of larger communities. In contrast, health issues arising from small community and private water supply systems such as individual households' cisterns or wells are harder to assess and, in general, regulatory frameworks focus less on their protection (Kreutzwiser et al. 2011). This is a major issue given that Statistics Canada (2007) estimated that 5 million Canadians receive drinking water from small, decentralized systems each serving less than 300 people. Additionally, the Burnside report (2011) estimated that 26% of homes on First Nations in Saskatchewan are on a decentralized system. This value agrees with Duncan and Bowden (2009) that estimated 25% of prairie reserve lands are dependent on hauling water, which they call the "prairie problem".

There are several components of a community's water distribution system that can lead to the creation of high risk to human health due to poor water quality. For example, even if a community has an effective water treatment plant that produces safe drinking water, the lack of a centralized distribution via high-pressure piping leads to individual homes lacking safe water. Overall, the majority of First Nations in Saskatchewan have homes on a decentralized water distribution system (Burnside 2011) that has various stages involved in transporting treated water from the water treatment plant to household taps that can result in contamination. Firstly, water is collected in a truck from the plant and then delivered to holding tanks (cisterns) to individual homes. Contamination of the clean water can occur during the filling of the truck or the filling of the households' holding tanks. Secondly, if the cistern is not properly maintained or replaced at the end of its lifecycle, it can fail in keeping out contamination such as pathogens, fecal matter, and chemicals. Additionally, when water delivery trucks are down for maintenance the community has to ration their water. Further, low-pressure centralized distribution overcomes the truck-related issues but still has the cistern issues given the water is distributed to the homes at low-pressure and generally stored in cisterns prior to use.

1.3 Economic Burden of Illness/Cost of Intervention

A lack of access to safe drinking water has the potential for creating negative health effects that have intrinsic economic consequences. The most common illnesses associated with waterborne pathogens are gastrointestinal issues with associated direct or indirect costs that have been determined previously. Direct costs may include: prescription medication, over the counter treatments, and provision of alternative water (usually bottled water). Indirect costs can include: lost time from work for the sick and their caregivers, lost business, and travel costs to healthcare providers (WHO 2012). A 2006 study of these costs estimated the economic burden to be $1,089 per case (all dollar values in CDN unless otherwise stated) with an annual cost per capita of $115 (Majowicz 2006). Comparatively, a 2008 study of a British Columbia town found similar results for cost per case and annual cost per capita as $1,342 and $130, respectively (Henson et al. 2008). These costs are typical for a household, but the economic burden is greater when an outbreak occurs impacting an entire water system. For example, a Cryptosporidium outbreak in Ireland was reported to have a cost of USD$142,000/day during a 158-day boil water advisory (Chyzheuskaya et al. 2017). During a 1993 outbreak in Milwaukee, WI, data from 11 hospitals showed that mild, moderate, and severe illnesses had total costs of USD$116, USD$475, and USD$7,808, respectively (Corso 2003). The impacts of these types of outbreaks have been used to exhibit that the costs associated with reactive treatment of illnesses are often higher than costs associated with proactive infrastructure upgrades that would help to eliminate illnesses before they occur.

Intervention with water infrastructure can reduce the economic burden associated with illness. The World Health Organization estimates that with USD$11.3 billion of infrastructure upgrades that the worldwide annual savings would be USD$84 billion for elimination and/or reduction of costs for health-related treatments. However, the savings are region-specific making direct comparisons to Canadian infrastructure potentially incorrect. A more realistic comparison would be with the United States where the projected annual cost to get the entire population onto a piped network of water and sewer is USD$2.32 billion with a benefit of USD$9.01 billion (WHO 2012). Failing and/or inadequate water systems on Canadian First Nations have gained notice by all levels of government with intervention efforts in the form of regulations and budget allocations. For example, the Canadian Federal government allocated $600 million over five years to support the 2003 First Nations Water Management Strategy (SDWF 2008). However, these efforts have arguably fallen short of expectations across Canada. For example, by 2011 25% of water systems in Saskatchewan were still in a state likely to cause health concerns and drinking water advisories (INAC 2011).

1.4 Current Funding Framework

First Nations Infrastructure projects are currently primarily funded by INAC's Capital Facilities Management Plan. The Cost Reference Manual (CRM) (2005) is an updated tool created by INAC in 1978 for the use for/by communities to estimate facility costs and to aid in planning for capital projects. This manual applies costs to components of a project (see Table 1) based on values typical for construction in Toronto, Ontario. Multipliers to these values are applied based on the 'remoteness' of a community that is determined by the distance of the community from the nearest 'city centre'. For communities in Saskatchewan these city centres include Regina, Prince Albert, Saskatoon, and The Pas (located in Manitoba). This remoteness factor allows for a percentage of the cost of up to twice the amount of the Toronto model. Additionally, other site-specific indices are applied based on the nature of the site; required transport methods; and construction schedule, personnel, and administration. An example of this application is shown in Table 1.

The value for each criteria is multiplied by the other criteria to determine the site-specific indices for a project as follows:

[1] Site Specific Index = $\sum(a) * \sum(b) * \sum(c) * \sum(d) * \sum(e) * \sum(f)$

For example, a Saskatchewan community in remoteness zone 2, 50km-350km from nearest city, and with the maximum site-specific indices shown in Table 1 would have its calculated project cost multiplied by a factor of 1.20.

Funds for water infrastructure projects are allocated by this method up to a maximum of $10,000 dollars per home plus 50% of the housing connection price. To qualify for centralized, high pressure piped water, the density of homes must average 3 units per acre and lot frontage cannot be more than 30 m (INAC 2011) with alternative systems considered when density decreases past this point. These alternatives include decentralized systems (trucked water) and more limited centralized low diameter piped and low pressure piped water systems requiring cisterns. Based on INAC's Level of Service Standards, funding decisions are based on the lowest life cycle costing of these alternatives for a 20-year term.

Table 1: Example of the Calculation and Application of Site Specific Multipliers

Criteria		Multiplier %
(a) Materials	Lumber Not Locally Available	2
	Locally Available Aggregates	0
	Building Supplies Not Locally Available	1
(b) Administration	Restricted Lead Time	1
(c) Nature of Site	Normal Soil	0
	Level and Treed	1
(d) Transportation	Road	0
(e) Personnel	Semi-skilled and Unskilled Labour	1
(f) Accommodation	Within Daily Travel	4

2 METHODOLOGY

The overall goal of this research was to compare the funding formula used by INAC to fund water infrastructure to an updated formula meant to reflect the true cost of this infrastructure for a community. The INAC funding formula was taken from the 2005 CRM that provides Class C and Class D cost estimates for indicated infrastructure maintenance and/or upgrades. The item costs used were taken from the 'Water Supply, Treatment, and Distribution' section of the Facility Unit Costs in the Capital Cost Manual. The item costs from the CRM were compared to item costs from other industry sources to determine if there was any association between sources and/or justification of the values given in the CRM given the lack of referencing to real-world costs in this manual. The values from the CRM (2005) were compared to a recently completed water distribution project on a First Nation in Saskatchewan (2012), an analysis of three contractor bids for water service to a subdivision and low density layout on a First Nation in Saskatchewan (2011) and a feasibility study of a low pressure distribution system for a Saskatchewan First Nation (2017).

Only values from the CRM were used to calculate the capital cost of distribution systems to help maintain consistency. The total construction cost was then multiplied by the remoteness index and site-specific indices dependent on the project location. The following equation shows how the total cost was derived using the current funding formula:

[2] CRM Cost = (Construction Cost)*(Remoteness Index)*(Site Specific Indices)

The values derived in comparison to this manual are also Class C and Class D cost estimates. The updated funding formula includes values beyond construction by including economic burden of disease, operation and maintenance of water delivery trucks, and impact on road infrastructure. These added costs are not meant to be exhaustive, they only serve as a first step to full cost accounting that currently excludes a number of relevant costs.

[3] Modified CRM Cost = (Construction Cost) + (Cost of Illness) + (Water Truck Maintenance) + (Increased Road Maintenance)

These formulas were applied to an example community of 100 homes (Figure 1) and using an average of 5 people/household as indicated by Statistics Canada (2011). The density of these homes is typical for rural households and piping lengths are based on similarly sized projects. The values for construction were taken from the CRM and were applied to compare the capital cost of centralized and decentralized systems.

Figure 1 shows what a typical community would look like with homes marked as grey boxes. Typically, the homes in higher density subdivision style layouts near the water treatment plant would receive piped, high pressure water (based on their higher density) and homes in a more rural (i.e., less dense) layout have cisterns. The centralized system calculation determines the cost to pipe water to all homes including the low density rural layouts. This schematic is based on a community similar in layout and density to allow for comparison of the capital cost for centralized and decentralized systems.

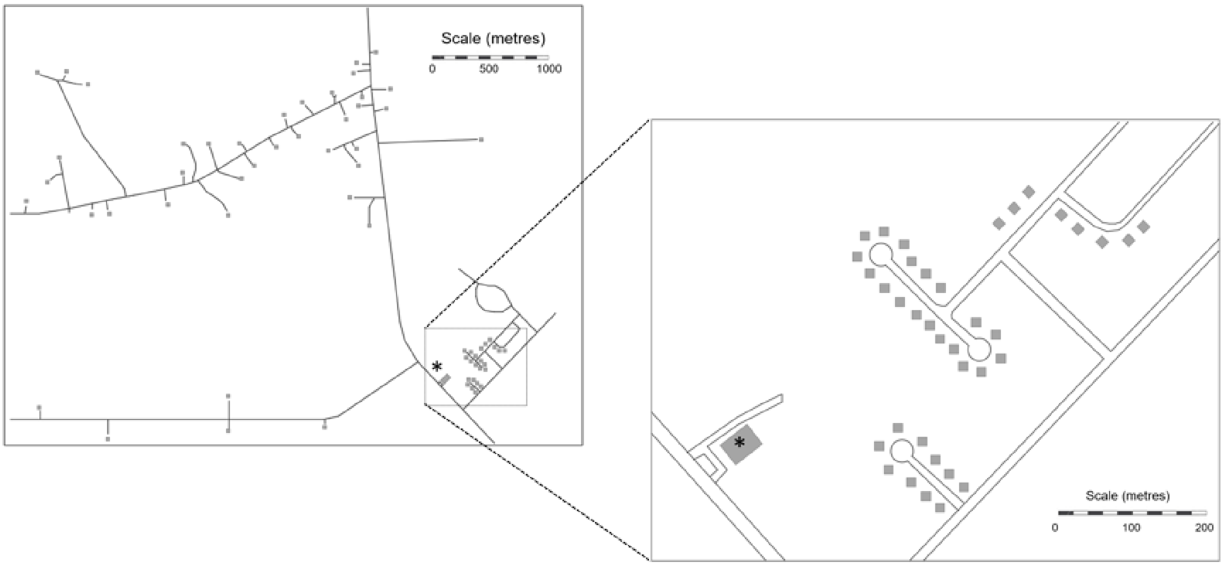

Figure 1: Schematic of Sample Community for Example Density and Layouts
(* Indicates the water treatment plant)

It should be noted that Figure 1, although representative of an actual community, shows a distinct difference between the preferred living/household arrangements (anecdotally, subdivisions are not preferred) and the water distribution systems' usage. The homes near the water treatment plant, typically the only ones on centralized system, are shown in the inset figure. This shows how a community's living arrangements are dictated by water service rather than suiting water service to a more preferred, rural housing layout. The 'subdivision style' layout is used to meet the requirements for funding of a centralized system based on the lowest schedule of services from INAC. However, traditionally people on First Nations choose to live spread out in family units (McLoud 2005).

The updated formula was applied in addition to the capital cost for the decentralized system as shown in eq. 3. The value for the cost of illness ($130) was taken from a study of economic impact of gastrointestinal illness on a Canadian community (Henson 2008). This value was then adjusted to account for increased occurrence, greater travel costs and psychological impacts that translate to a Saskatchewan First Nation community (Patrick 2010, Plummer et al. 2011, Reynolds et al. 2008). The operation and maintenance costs for water delivery trucks are allocated to communities based on the Capital Asset Inventory System. A sample agreement of what a typical heavy hauler truck would pay a municipality for its impact on rural roads was used to estimate the cost of extra maintenance and loss of road life from daily hauling of water in the First Nation community (Ministry of Highways 2013). The updated formula is applied over a proposed lifetime of 20 years (based on INAC's Lifecycle Cost) to show the ongoing impact and justify greater capital.

Please note that the sources of the monetary values being compared are from different years and have therefore been adjusted for inflation using the consumer price index from the Department of Finance's Private Sector Survey (Department of Finance 2017).

3 RESULTS

Values and formulas presented above were examined to help better understand the overall funding process and to assess its validity. Cost of materials and methodology common to water infrastructure projects were compared to determine the basis of the CRM values and see if they were similar to other sources. The results are divided into three sections: updating of the funding formula; application to an example community; and comparison of common values. The first section shows how the funding of water infrastructure projects can be expanded to reflect a truer actual cost of the infrastructure's lifetime. The second section applies this updated funding formula to an example community to compare cost over a lifecycle of 20 years. The last section provides an overview of the values used in the funding formula from the CRM that were compared to costs of methods and materials from other industry sources on water infrastructure projects to see how accurate the CRM is in estimating projects in Saskatchewan.

3.1 Updated CRM Funding Formula

The CRM funding formula was updated to include indices other than construction costs taken from relevant studies (Henson 2008; Ministry of Highways 2013; INAC 2011) for potential health impacts of contaminated water including the cost of gastrointestinal disease treatment, the operation and maintenance of water delivery trucks, and the increased road maintenance costs related to heavy water truck delivery impacts on community roads. These indices are not meant to be exhaustive in their extent of other issues but serve as a first step towards updating the CRM formula to more realistically portray the true costs. Additionally, despite the inadequacies of the CRM indicated previously, its use for comparisons between centralized and decentralized systems was acceptable given it allows for standardization of the various unit costs shown in Table 1.

Clean drinking water can be contaminated in various stages of a decentralized water system including during the filling of the water delivery truck, during the filling of cisterns, and within the cisterns. The contamination during the delivery process can be remedied via proper connections between the various water containers and having properly trained operators making the transfer. Unfortunately, cisterns at the home are prone to contamination (e.g., animals entering the cisterns) as the collars get damaged or the access is not securely restricted. It has been shown that some communities using cisterns that have been improperly installed have drinking water advisories from their installation date (Baird et al. 2013). The most common illnesses from drinking water issues are gastrointestinal with direct costs for medication and visits to health care professionals and indirect costs due to loss of work time and travel to health services. Henson's (2008) study on the direct and indirect cost of gastrointestinal illness in a British Columbia community found these costs to be $130 per capita annually. This value is conservative given that it is estimated that only 5% of gastrointestinal illnesses are reported and treated (Reynolds et al. 2008). However, contamination, and therefore related illness, is 2.5 times more likely on First Nations than other Canadian communities (Patrick 2010). Further, there are other water-related issues such as skin rashes that are not considered (Plummer et al. 2011). Currently, we tripled the costs to $390 per capita annually based on Henson's study community to a Saskatchewan First Nation to better account for the increased frequency of contamination, other types of physical and psychological illness, and remoteness of these communities. This initial increase is arguably subjective in nature needing further validation, however, serves as a reasonable first approximation based on the costs provided by Henson (2008) and the higher risk provided by Patrick (2010).

Other costs added to the funding formula are the operation and maintenance of water delivery trucks and the roads impacted by the heavy trucks. From the CRM, the purchase of a new water delivery truck is approximately $160,000 and the annual funds provided for maintenance is $1,000 per cistern, based on the Capital Asset Inventory System from INAC. Hauling water is a burden on the operation and maintenance capacity of the community requiring about one truck for every 50 cisterns. These trucks are prone to breaking down as they are under heavy demand leaving the community to ration water when they are unavailable and/or or to pay for water from other sources (e.g., bottled water). The impact that these vehicles have travelling daily on gravel roads can increase the road maintenance cost for a community as well as decrease the life of the roads. Saskatchewan Ministry of Highways (2013) suggests compensation of $82.26/km for hauling in the summer and $41.13/km hauling in the winter to municipalities for heavy trucks their impact on rural roads. These values were used in the updated cost formula to account for the impact of the water delivery trucks on community roads.

3.2 Application to a Sample Community

As a case study, a comparison was made using the CRM for centralized (Table 2) and decentralized (Table 3) distribution using the values for a community project of approximately 100 homes and 500 people. The quantities used for these calculations include information from a project brief of a low pressure water distribution system that was completed on a First Nation in Saskatchewan in 2011 (Consultant A 2012). This project serviced 100 homes with density typical to rural residences on First Nations. This simple cost estimate does not include all project expenses but is limited to what the CRM has defined. However, we assumed that components absent from a more complete estimate would be similar in value to what would be absent from a decentralized project. Table 2 shows an initial capital cost of approximately $30,000 per home ($2.8 million total) which is three times the amount ($10,000) that is typically allocated for water infrastructure projects.

Table 2: Application of CRM to Calculate Capital Cost of an Example Centralized Distribution System

Item		Units	Quantity	Unit Cost ($)	Total ($)
Installed Pipe	25mm	m	1,040	57	59,280
	38mm	m	18,300	69	1,262,700
	50mm	m	10,100	80	808,000
	75mm	m	2,700	100	270,000
	100mm	m	8,700	118	1,026,600
Isolation Valves	38mm	ea.	9	853	7,677
	50mm	ea.	11	853	9,383
	75mm	ea.	2	853	1,706
	100mm	ea.	6	853	5,118
Curbstops		ea.	100	278	27,800
Air release valves		ea.	6	5,600	33,600
				Total	3,511,864

In Table 3 the total capital cost is in close agreement ($13,648) with the typical allocation of $10,000 per home considered by INAC. However, this price could vary by community for the size of cistern and number of water delivery trucks.

Table 3: Application of CRM to Calculate Capital Cost of an Example Decentralized System

Item	Units	Quantity	Unit Cost ($)	Total ($)
Cistern (4500L)	ea.	100	5460	546,000
Housing Connection	ea.	100	5000	500,000
Water Delivery Truck	ea.	2	159,420	318,840
			Total	1,364,840

In addition to the initial capital cost of a decentralized system shown in Table 3, other annual costs were added to reflect the true cost of the system to the community (Table 4). Operation and maintenance values do not include routine maintenance of cisterns. The CAIS does not currently provide any operation and maintenance funding to low pressure distribution systems so for equal comparison it was omitted from decentralized systems as well. The amount of funding allocated for operation and maintenance of water delivery trucks is dependent on the number of cisterns and not the number of delivery trucks. This funding includes operator wages, fuel, and maintenance.

Table 4: Extra Annual Costs Associated with Decentralized System

Item	Units	Quantity	Unit Cost ($)	Total ($)
Cost of Illness	per capita	500	457	228, 500
Vehicle Maintenance	per cistern	100	1,000	100,000
Road Maintenance (summer)	km	1825	88	160,600
Road Maintenance (winter)	km	1825	44	80,300
			Total	569,400

Overall, the capital cost of a centralized system is $3.51 million and the capital cost of a decentralized system is $1.36 million. Starting from the capital costs, the annual costs of operation and maintenance can be added to each system over time to more accurately show the infrastructure costs over the 20 year lifetime (Fig. 2). The extra annual cost of a decentralized system is $569,400 with the largest portion ($240,900) attributed to the maintenance of roads which is already an issue for many communities. However, the cost of illness is also significant at $228,500 /year. Overall, the greater capital cost of a centralized system is justified in a short time at roughly four years (point of intersection of the systems in Fig. 2).

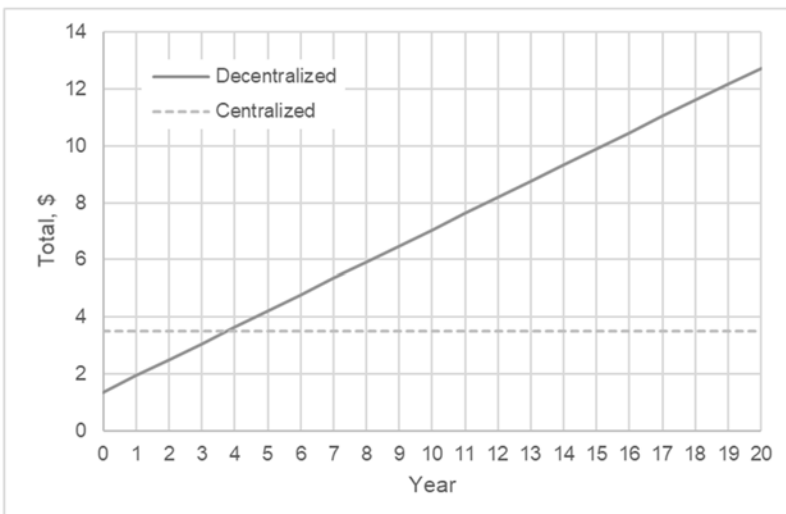

Figure 2: Annual Cost of Centralized and Decentralized Water Distribution (Values in Millions)

3.3 Comparison of Common Values

Common values for construction methods and materials used in water infrastructure projects were compared to see if there was any association or consistency in their determination. The sources that were compared were: INAC's Cost Reference Manual (2005), a completed rural centralized distribution project (2012), a feasibility study for centralized distribution (2017), and a bid analysis of three contractor's bids on a water infrastructure project (2011).

Table 5: Comparison of Values of Common Materials and Methods from Various Industry Sources

Item	Unit	2018 Value (CAD/unit)				
		INAC CRM	Community Project	Consultant	Contractor High	Contractor Low
Trench	m	*	33	96	196	95
Plough	m	*	11	30	N/A	N/A

25mm Pipe**	m	57	34	102	230	112
50mm Pipe**	m	80	35	103	N/A	N/A
75mm Pipe**	m	100	42	106	N/A	N/A
Gate Valve	ea.	852	330	N/A	N/A	N/A

* CRM includes only the cost of installed pipe and does not specify by which method
** Values for piping include the cost of installation

Clearly, general comparisons for each metric indicate no strong association between values for sources. The highest overall values were from contractors but the three contractor bids analyzed varied significantly. The CRM values were lower than the consultant and contractor bids indicating their inaccuracy given these values should align with actual costs. Interestingly, the lowest values were for the community infrastructure project that indicates the possibility of providing a centralized system for less than the CRM or an engineering consultant estimated costs. This lower price appears to be due to a source of inexpensive material that limited costs for the specific project. The consultant's feasibility study relates to the least expensive contractor. However, it is acknowledged that values for water infrastructure projects vary dependent on economic, geographic, political, and social factors making it difficult to generalize for projects on a national level and requires unique examination for every project.

4 CONCLUSIONS

Overall, it was determined that the INAC Capital Facilities Management Plan and CRM inadequately determines the cost of water infrastructure in Saskatchewan (and likely throughout Canada). The fundamental flaw with CRM is indexing all parameters to the urban Toronto example. Altus Group provides a construction cost index every year and is considered to be an industry standard (Altus Group 2017). Using the values from this report and looking at data from Statistics Canada, it is shown that the cost of labour and materials for new construction varies year to year and by geography. Clearly, there is no simple, linear method to relate values from one city to another year by year as is done with the CRM. In general, the determination of index values from the CRM is neither referenced or justified and appears arbitrary lacking these details. Additionally, the multipliers are not justified for use year-over-year and, even if justified, the CRM is out-of-date with the most recent revision done over a decade ago in 2005.

In general, there is insufficient funding for both capital projects and ongoing operation and maintenance of water systems on First Nations. Trucked water and household cisterns are the lowest cost based on capital but these systems pose a greater impact to community health and infrastructure in the years after installation. Estimating for only construction cost has failed to provide technical systems that succeed long term and is more costly long term based on the true costs presented here. The greater capital cost of a centralized system is justified considering the extra costs from failing decentralized systems and that fact that extra capital costs are recovered within approximately 4 years. The benefits to human health and ensuring safe drinking water for a community is worth the extra investment on its own but this research has found it economically justified as well.

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