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Article

A Tale of Two Communities: Adopting and Paying for an In-Home Non-Potable Water Reuse System in Rural Alaska

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ABSTRACT: Several rural communities in Alaska lack piped water and sewer services ("unserved"), leading to residents self-hauling drinking water and manually disposing of waste. Being time and labor intensive, these practices result in extremely low household water use and detrimental health impacts, leading to wash disease rates that are higher than those of communities with piped water and sewer systems. This study reports on results from community meetings and surveys held in two unserved rural Alaska communities to evaluate perceptions of water reuse and the willingness to pay for an in-home water reuse system to identify possible price points they are willing to accept. The survey was designed to iteratively understand which water fixtures households desired and at what cost. Survey results showed that in-home water/sewer infrastructure may cost more than community members are willing or able to pay. There are also regional differences in acceptable costs and preferences for specific water fixtures. The results also suggest myriad local factors that may impact acceptance, desire, and willingness to pay for in-home water reuse. Overall, this work highlights the importance of community input and engagement as well as assessment of community needs and readiness while developing technological solutions for rural communities in Alaska and beyond.

KEYWORDS: *willingness-to-pay, decision making, water reuse, end user, cooperative fee, rural Alaska*

1. INTRODUCTION

While 99.6% of American households can mindlessly turn on a tap in their homes,[1] more than 1 million Americans, equivalent to the country's seventh largest city, lack access to running water.[2,3] In Alaska, overall 4% of households and 20% of rural homes lack access to in-home plumbing facilities and, consequently, running water and sewer services,[1] the highest rate in the country.[4]

A majority of Alaska households lacking access to water and wastewater services are rural and are located in the 31 unserved Alaska communities.[5] The Alaska Department of Environmental Conversation (ADEC) classifies communities with >45% of households relying on self-haul as unserved.[3,6] In self-haul systems, residents haul water, store it in their homes, and haul waste from their homes. Hauling is done using four-wheelers or snow machines or "by hand".[7] Some communities also have rainwater collection systems.[8,9] Instead of toilets, residents use 5 gallon buckets called "honey buckets" and dispose of the human waste in community wastewater lagoons or community honey bucket hoppers.[10] Even in served communities, where most households are connected to piped water and sewer services, some households may be disconnected from piped services. Most communities have a washeteria, a centralized facility for obtaining treated water, showering, and doing laundry.

In self-haul communities, water consumption rates appear to be significantly lower than the national average of 80−100 gallons day^{-1} person^{-1}.[11] Hauling water is time and labor intensive, and households are limited in how much water they can store. In some unserved Western Alaska communities the consumption rates are closer to 1.5 gallons capita^{-1} day^{-1}. In the Northwest Arctic Borough, a survey of 21 households revealed an average reported consumption of 2.4 gallons capita^{-1} day^{-1} with consumption ranging between 0.4 and 7.1 gallons capita^{-1} day^{-1}.[7] In four Western Alaska communities, water usage rates increased to 9.2−37.9 gallons capita^{-1} day^{-1} after the construction of a piped system.[9]

Lack of access to water and wastewater services impacts the health of residents in Alaska communities. While the rural Alaska rates of infectious diarrheal hospitalizations, considered waterborne diseases, are comparable to the U.S. national average,[12,13] rates of hospitalization due to water wash diseases are higher. Water wash diseases, such as skin irritations, respiratory infections, and gastrointestinal illnesses, are more

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common[14] and result from limitations in the quantity of water available for consumption. When in-home water services became available to previously unserved households in Western Alaska, community rates of clinic visits declined by 38% for gastrointestinal illnesses, 16% for respiratory infections, and 20% for skin infections.[14]

Despite the health benefits of providing water and wastewater services in rural Alaskan communities, funding for capital construction of centralized systems has declined and the cost of water and sewer services has increased. Additionally, the remaining unserved communities are the most remote and most expensive to serve,[15] and it will cost state or federal authorities $200,000-$400,000 per unit to provide service in these communities.[16] The estimated deficit between available funds and capital costs is more than $2 billion.[17] Additionally, building and maintaining small-scale water and wastewater infrastructure in unserved and underserved communities is difficult. Most of these communities are isolated and off the road system and can be accessed by only air or seasonal barges. Extreme temperature variations between seasons and winter temperatures of −40 °F in winter require engineering designs to be adapted.[18] Permafrost thawing adds another layer of complexity and further increases costs. Communities also experience challenges operating and managing water utilities. Many rural utilities struggle to recruit and keep operators, as these positions are part-time and require extensive training and certification.[15] Rural residents and local governments have limited cash-generating opportunities. Communities are also dependent on dwindling grants and externally determined funding priorities to maintain, repair, and upgrade community infrastructure.[19]

Given the complexity and expense of providing service to unserved communities, in 2013 ADEC launched the Alaska Water and Sewer Challenge (AWSC) to develop novel in-home reuse water systems that are less expensive to install and operate than conventional piped systems. ADEC set specific cost parameters. ADEC would pay the fabrication and installation costs of the system, which is estimated to cost at most $135,000 per home. Households are responsible for paying the monthly operating costs, which should be less $135, including a $40 cooperative fee. The utility cooperative would store spare parts and tools and provide support for operation and maintenance. The water reuse system discussed in this paper was one of the finalists in response to the ADEC challenge. Community engagement and end-user feedback were deemed to be essential to the AWSC's success as water systems that meet community needs are more likely to be ultimately adopted and maintained.

The AWSC parameters require households to accept the concept of water reuse and the installation of in-home systems. While water reuse already occurs with repeated handwashing in the same volume of water or repurposing used water for lower-quality activities, one focus of the AWSC was discussing the technological concept of water reuse with rural Alaska households. We prepared for the possibility that the concept of reusing all water, except for wastewater, could evoke the same "yuck factor" that has been observed in U.S. states like California that introduced direct potable reuse.[20] In addition, we prepared for the need to address the community's desire to continue using traditional water sources and potential concerns about chemical additives.[21] While several studies have been undertaken globally to investigate the economic and technological aspects of adopting water reuse,[22−24] very few have looked at public perceptions and those have been primarily limited to urban areas.[25]

This study occurred in two phases. In phase 1, willingness to accept in-home water reuse was captured through community meetings in two unserved communities. However, installation of an in-home system is unlikely to result in behavioral changes on its own. Community decisions around water services are complex, and it is important to understand end users' ability and desire to pay for services. A community may not be ready to adopt sanitation upgrades if the cost outweighs the perceived benefit. In phase 2, households in the two communities were given a survey to evaluate their willingness to pay for the in-home treatment system developed by the University of Alaska Anchorage and their desire for specific fixtures based on the costs they were willing to incur. It is important to note that in this article the term willingness to pay has a colloquial meaning, rather than the specific definition ascribed to the term by economists. Overall, the results from this work highlight the importance of community input and engagement as well as assessment of community needs and readiness while developing technological solutions for rural communities in Alaska and beyond. The team has continued to develop this system, and the current prototype is different than the one described in this study.

2. METHODS

This research involved meetings, collecting information about energy costs and prototype usage, and a willingness to pay survey in two rural Alaska communities (IRB Exempt Number 1133794). Study methods and the timeline are schematically represented in Figure 1. The communities and methods are described in detail below.

2.1. Participating Communities. The UAA team collaborated on this research project with two unserved communities: one in the Yukon-Kuskokwim Delta (YK) near

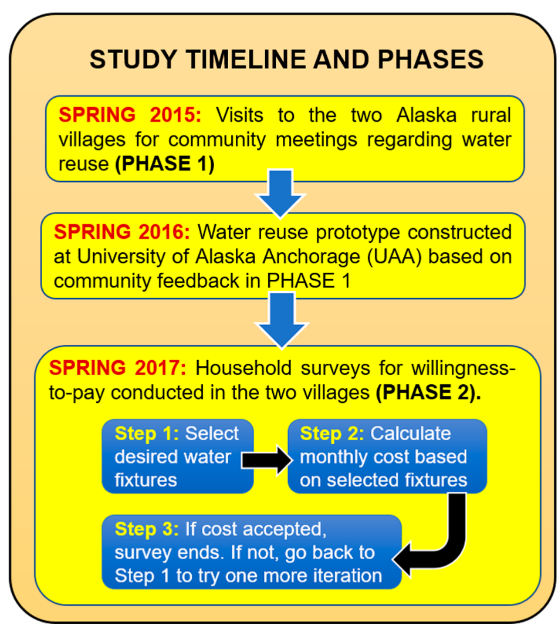

Figure 1. Schematic representation of the study timeline and phases.

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the coast of the Bering Sea and the other in Interior Alaska. The water scenario in each community is described below.

2.1.1. YK Delta Community. The YK community is predominantly Yup'ik and in 2016 had 682 residents and 168 households.[26,27] This community is off the road system and can be accessed by only planes and seasonal barges. The YK community has a boardwalk system, and residents use four-wheelers and snow machines for within-community transportation. The community operates a washeteria that has community toilets, showers, and laundry on a pay-per-use basis and bulk purchasing of treated water for in-home use. The water plant at the YK community treats surface water from a lined pond that is configured to accumulate snow during the winter and uses direct filtration via peroxidation and subsequent disinfection with hypochlorite.[28] The treated water is also piped to the local health clinic. The local school is supplied water from a separate water treatment facility. The community maintains a facultative wastewater lagoon outside of the community that can be accessed by the boardwalk. Wastewater from the washeteria, clinic, and school is piped to the lagoon, while wastewater generated by community members is self-hauled and poured into the lagoon via a discharge location. Households utilize a honey bucket for collection of human waste and another bucket for collection of kitchen waste and graywater. Households dispose of full honey buckets in a community honey bucket hopper, which is periodically towed by four-wheeler to the lagoon by community workers. Some dispose of honey bucket waste directly into the lagoon. Households often dispose of kitchen waste and graywater on site. Most of the households practice rainwater collection during the summer and fall.

2.1.2. Interior Community. The Interior community is predominantly Hut'aane (Koyukon) Athabascan, with 79 residents and 39 households in 2016.[26,27] Like the YK community, this community is also off the road system and can be accessed by only planes and seasonal barges. The Interior community has roads on which cars and trucks can drive, but residents also use four-wheelers and snow machines for within-community transportation. The Interior community's washeteria treats groundwater with granular activated carbon, granular filtration, and oxidation/disinfection with sodium hypochlorite.[28] The washeteria provides community toilets and showers for free to community members and laundry facilities on a pay-per-use basis. The treated water is piped to the local health clinic, the school, and a community tap. Community members bring their own containers to the community tap and collect water free of charge for personal use; cost of provision is currently subsidized by the local government. There is a wastewater lagoon near the community that is for only wastewater disposed by the clinic, school, and washeteria. Most households maintain an outhouse near their home and often use a honey bucket within their home during winter. Full honey buckets are emptied into the household's latrine when full. Households often dispose of kitchen wastewater and graywater on site. Many households collect rainwater during the summer and fall.

2.2. Phase 1: Community Visits and End-User Feedback on Water Reuse. The research team visited the Interior community during April 20−22, 2015, and the YK community during April 6−8, 2015, to help community members conceptualize an in-home water reuse system as an alternative solution to graywater disposal. The team used the "design thinking" model to solicit community collaboration in the design of the in-home water reuse system. At the community events, alternative solutions to centralized water systems for water and wastewater, existing community water reuse practices, and national safe water reuse practices were discussed. The community actively participated in the discussion, and the research team solicited end-user design ideas that might be incorporated into the in-home solution that would meet the specific needs of the communities. The community discussions were held in the tribal offices and the schools. To encourage participation, the discussions were announced via flyers and VHF radio, and the events featured food and door prizes. The discussion participants were also asked to respond to a survey. The community input directly affected the design of the research team's prototype of the water reuse system. The only costs discussed during the phase 1 community meetings were the ADEC cost guidelines.

2.3. Construction and Operation of a Prototype System. During the spring of 2016, a prototype was constructed on the basis of the community feedback using best engineering practices. The prototype was continuously modified until it could meet the water quality guidelines defined by ADEC and the team's vision of a treatment process meeting direct potable reuse standards. The prototype configuration was tested from October 2016 to July 2017. During this period, the prototype was configured such that graywater was generated by the NSF-350 graywater composition[29] and a team-generated kitchen sink recipe. Graywater was treated by the prototype using physical soap removal with a modified protein skimmer, three-stage cartridge filtration (5, 1, and 0.5 μm), nanofiltration, reverse osmosis, ultraviolet disinfection, and periodic ozonation. Graywater was treated once daily to supply enough wash water for the following day. The toilet was a commercially available urine diverting dry toilet (UDDT) manufactured by Separett. Drinking water was treated within the home using a 1 μm cartridge filter followed by ultraviolet disinfection. The system was operated according to a variety of loading sequences that loosely follow NSF-350 and was configured to supply 58 gallons per day of wash water and 2 gallons per day of drinking water. This operational volume was selected to mimic a household of four using 15 gallons person^{-1} day^{-1}. While a reduced volume, this amount of water provided an individual 14.5 gallons person^{-1} day^{-1}. For the household, this results in four 6 min showers, 10 gallons of kitchen sink water, 14 gallons of bathroom sink water, and one load of laundry per day. At the time of the survey, the membrane replacement frequency had not been determined and the associated cost was omitted from the survey.

2.4. Phase 2: Household Surveys Based on the Prototype System: Willingness to Pay for In-Home Water Reuse. *2.4.1. Cost Estimates for the Survey.* Energy cost estimates used in the survey were computed by collecting data on water input, water output, and prototype power consumption. Energy costs were monitored from August to December 2016 and again from February to March 2017 to account for seasonal variation. The prototype system was equipped with power monitors (Dwyer DPMP-403). The energy required to operate the water reuse system and the associated fixtures, which consisted of four water heaters, an all-in-one washer/dryer machine (LG 4.5), an air compressor, and a battery charger, was monitored. The power was converted to energy, kilowatt hours (kWh), assuming a power factor of unity and a line voltage of 120 V. The cost

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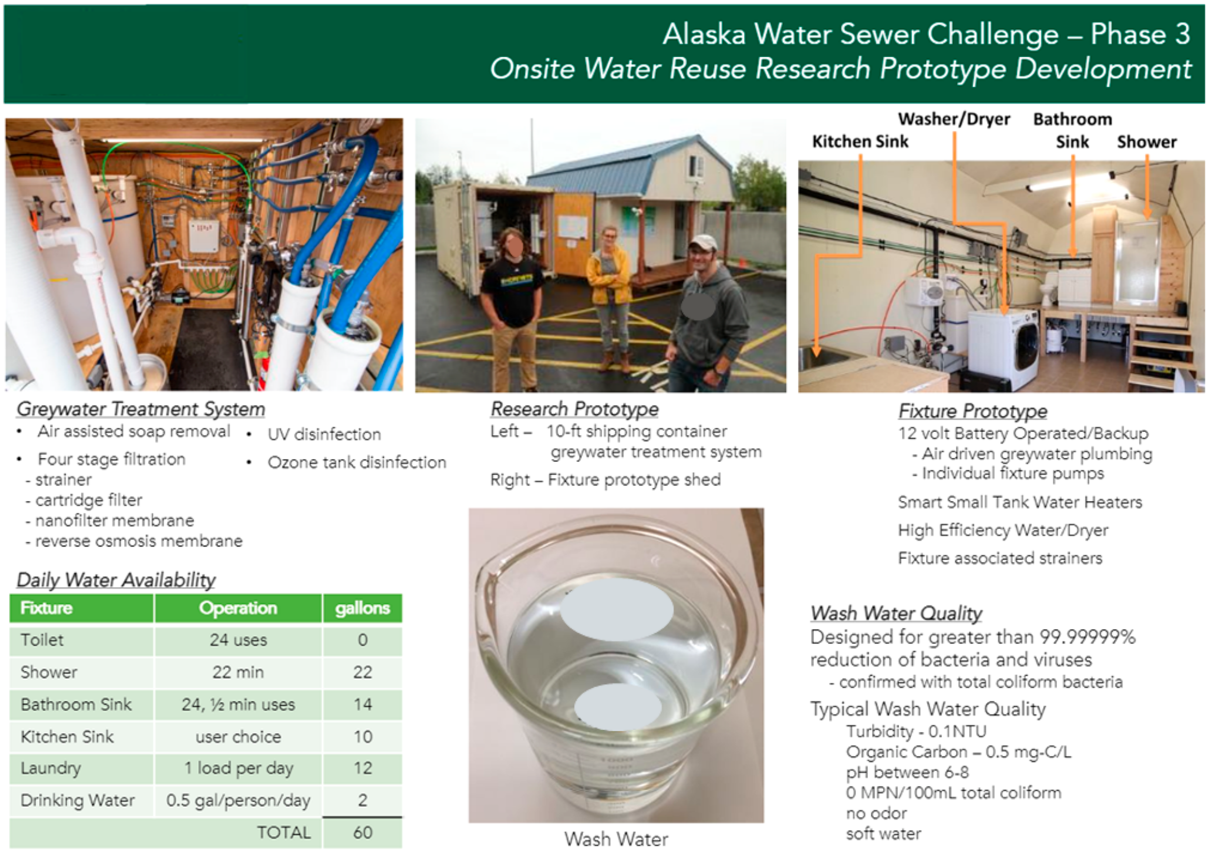

Figure 2. Onsite Water Reuse Research Prototype Development handout.

per kilowatt hour in each community varies dramatically across Alaska, and the survey used the projected use cost in each community. While the two communities are eligible for the rural Alaska electricity subsidy called power cost equalization (PCE), the survey used pre-PCE prices to generate conservative use cost estimates. Costs used in the survey were \$0.32/kWh in the YK community and \$0.95/kWh in the Interior community. The unit operating cost was estimated for each respondent by inputting the power use and water use (as calculated by households at 15 gallons person^{-1} day^{-1}). The unit cost was then used to calculate the actual operating costs for the household. The \$40 monthly cooperative cost was included in the cost estimates.

2.4.2. Protocol for Recruiting and Surveying Households. Survey respondents were recruited in collaboration with tribal leaders and city administrators. Flyers advertising the survey were displayed in the communities, and word-of-mouth recruitment occurred during community visits. The research team traveled to the YK community during March 24−26, 2017, and to the Interior community during April 18−19, 2017. Stratified random sampling divided the communities by roads and boardwalks. This sampling technique reduced the threat of survey bias, specifically the threat of under-representing or over-representing portions of the communities. Approximately every third house was approached on foot. If no one was home or if the household declined to participate, then the prior house was approached. No personal information was collected, and all results were aggregated to develop community-wide sentiment. Participation was voluntary. The surveyor required respondents to self-identify as the head of household and be at least 18 years of age. Couples participated together if they expressed a shared interest in the decision making process. Elders were surveyed using relatives as translators. Each household was given a gift card in compensation for their time upon completing the survey.

2.4.3. Implementation of Household Surveys. Households that agreed to participate were given a handout, Onsite Water Reuse Research Prototype Development (Figure 2), which displayed pictures and text describing the UAA water reuse system. The visual depictions of the prototype's fixtures were especially important in the YK community, where Yup'ik is people's primary language. The head of household was given time to look over the handout, front and back, and ask questions. After the head of household had been briefed on how the system operated, they were informed that the survey's intent was to determine the household's ability and desire to pay for access to in-home running water.

The willingness-to-pay survey had two parts. In the first part, household data that could influence the monthly costs of the water system, including the number of people in the home and the desired water source, were gathered, and respondents picked their desired fixtures. Options for fixtures were a kitchen sink, a bathroom sink, a shower, an all-in-one washer/dryer machine, and a urine-diverting dry toilet. No costs were displayed in the first part. In the second part, the fixtures and usage data were input into an Excel sheet to estimate the monthly costs of the desired system. Respondents then decided whether to accept the hypothetical costs. If the

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respondent accepted the costs, the survey ended. However, if the costs were unacceptable, the process began again and the respondents changed their choice of fixtures. In the second and all subsequent rounds, the monthly cooperative fee was negotiable. The Excel spreadsheet was updated with the new fixture choices until the head of household was provided with estimated monthly costs they were willing to pay.

3. RESULTS

On the basis of prototype operations at the time of the survey, ~1.4 kWh of power was used to treat water daily and ~5.3 kWh was used to operate fixtures daily on the basis of a four-person household. The majority of the household energy was used to heat water (~2 kWh/day) and to operate the laundry machine (~1 kWh/load). Under specific loading sequences with degrees of dirty filters, significantly higher electrical loads were observed (upward of 10 kWh). Similarly, when membranes were new and operational sequences required reduced water usage, power use was significantly reduced (~2 kWh).

3.1. YK Delta Community Results. In the YK Delta community, the community meeting was attended by 40−60 community members of all ages and 30 households were surveyed, representing approximately one-fifth of the community's households. In phase 1 community visits in the YK Delta Community, the team observed apprehension regarding in-home water reuse during the YK Delta community meeting. Acceptance of the reuse concept increased as indicated by a few attendees "nodding" that they would be willing to reuse water as local practices were explained. In particular, the reuse of handwashing basin water, which is used to wash multiple people's hands prior to disposal, served as an example of current reuse practices. In general, however, community members had to be convinced that water reuse was acceptable. Community members suggested that the research team would need to demonstrate the prototype prior to installation. Other general findings from the meeting included that the average household size was five persons. The home was rarely allowed to freeze in winter. Attendees anticipated on average each household would have ~17 showers per week and do approximately five loads of laundry (likely at the local laundry faculties that have commercial sized machines). Most attendees would accept the use of chlorine (57%) for disinfection and would accept lower-quality water for toilet flushing (95%).

In phase 2 household survey results on willingness to pay for in-home water reuse in the YK Delta community, most respondents (29 of 30) in the YK Delta community said they would be willing to pay a monthly fee for an in-home water reuse system and a urine-diverting dry toilet. One household reported not wanting in-home water or sewer because pipes freeze and break, causing more difficulties than using buckets. Thirteen of the respondents agreed to the initial monthly cost estimate, and the average acceptable monthly cost was $81.44 (Figure 6). The 17 other respondents did not agree to the initial monthly cost estimate, resulting in a "renegotiation" (Figure 3).

The average rejected initial monthly cost estimate was $85.12 (Figure 6). The average accepted monthly cost estimate after "renegotiation" was $54.97, a decrease of 36%. Overall, the average monthly cost that respondents were willing to pay was $66.84. The least desired monthly cost was the utility cooperative fee of $40 per month. Of the fixtures, the costs associated with the shower and laundry were least desired. The most desired fixtures were the kitchen sink, bathroom sink, and urine-diverting dry toilet. The respondents showed no interest in using washeteria water as a source for the reuse system. Washeteria water is typically paid for by the gallon and would therefore increase monthly costs. The preferred water sources were rain and ice, which have no direct costs. However, the surveys were conducted at a time of year when gathering ice for in-home water use was possible, which may have affected the responses.

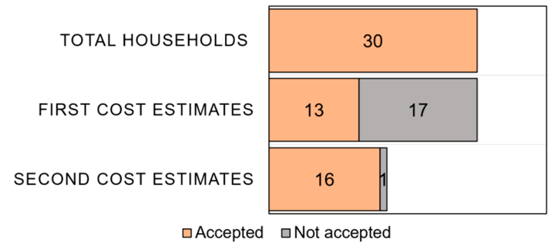

Figure 3. YK community willingness to pay (n = 30).

3.2. Interior Community Results. From the phase 1 community visits and meetings, the research team learned that the concept of water reuse was not widely accepted by the community and that additional opportunities to discuss the subject could be beneficial. Some community members expressed concern about the cost of operating a new system and preferred to continue self-hauling water if doing so resulted in a lower monetary cost. Other community members said they could afford the ADEC-suggested price of $135/month without objection. Other general findings from the meeting included that the average household size was 3.5 persons. Six households allowed their home to freeze in winter. Attendees anticipated that, on average, each household would have 8.5 showers per week and do 3.8 loads of laundry. Overall, 84% of the attendees were supportive of chlorine in the water reuse system (16 yes, 3 no) but were unsure about lower-quality water for toilet flushing (10 yes, 10 no) and also about timed showers (11 yes, 9 no). In phase 2 household survey results on willingness to pay for in-home water reuse in the Interior community, most respondents (10 of 11) were willing to pay for an in-home household reuse system. Only three were willing to pay for the initial monthly cost estimate (Figure 4), which averaged $87.62. The respondent who was unwilling to pay was exclusively interested in a well and septic system.

The seven respondents who "renegotiated" were willing to pay an average monthly cost estimate of $100.49, a decrease of 40% from an average of $166.92 in the initial cost estimate (Figure 6). Overall, the average monthly cost that respondents were willing to pay was $96.63. Most households were

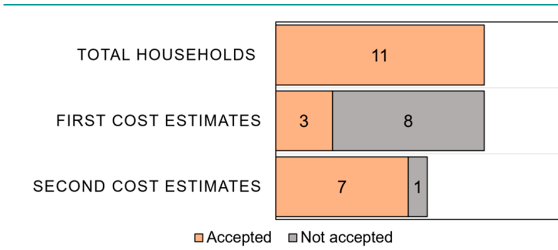

Figure 4. Interior community willingness to pay (n = 11).

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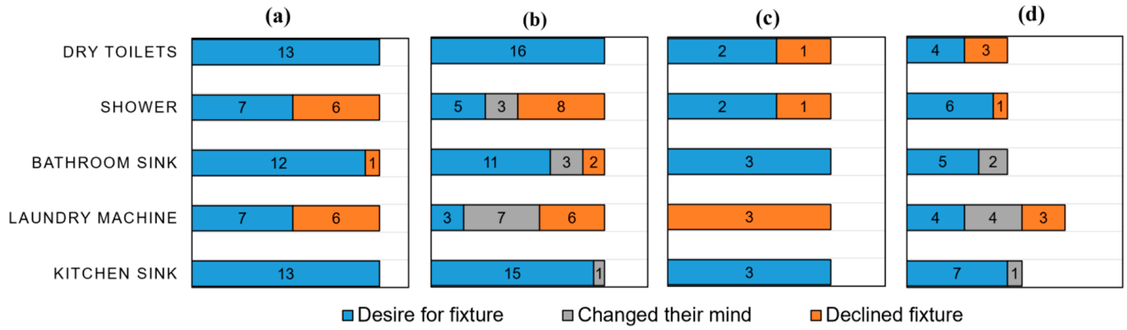

Figure 5. Summary of fixtures selected by community. (a) YK respondents' first selection of fixtures with no associated costs and willingness to pay (n = 13). (b) YK respondents' first selection and subsequent second selection of fixtures with associated costs (n = 16). (c) Interior respondents' first selection of fixtures with no associated costs and willingness to pay (n = 3). (d) Interior respondents' first selections and subsequent second selections of fixtures with associated costs (n = 8).

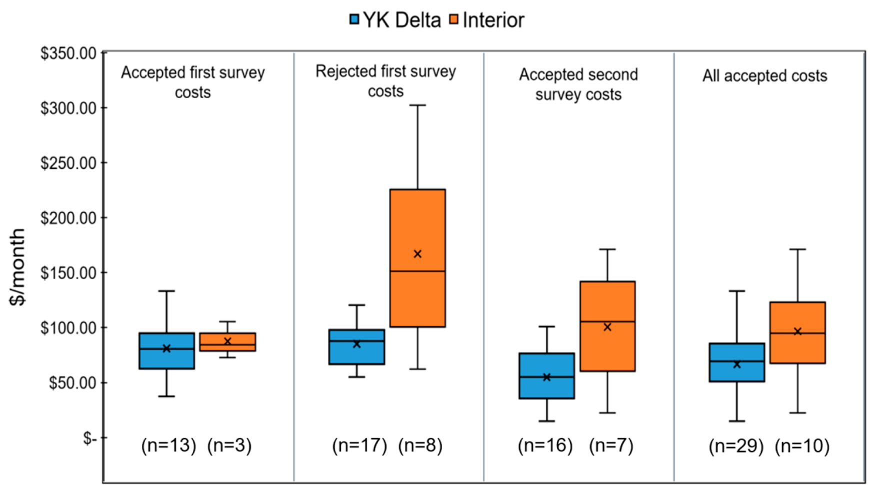

Figure 6. Box plots showing the variation of monthly costs homeowners were willing to pay during different stages of the surveys in the two communities.

interested in the urine-diverting dry toilet, with six respondents willing to include it as a fixture. The least desired fixture was the laundry machine, with respondents preferring to use the washeteria. Respondents were also generally willing to forego the bathroom sink but tended to keep their selection of a kitchen sink and a shower. In fact, no one opted out of the kitchen sink or shower fixtures during the "renegotiation". The least desired cost was again the utility cooperative fee of $40 per month. Five households renegotiated the cooperative fee during the second survey as being unnecessary. Fixture selections from both communities are shown in Figure 5.

4. DISCUSSION

The idea of water reuse in rural Alaska is not entirely new. As discussed during the community meetings and household visits, water was already being reused for handwashing and mopping floors. After further discussion of how water reuse could increase quantity and quality of in-home water, the idea gained more community support. Persistent explanations during community visits of the water reuse concept countered some initial negative reactions, and more dialogue could continue to increase community support. Researching end users' preferences helps to ensure the long-term success of the technology. By determining the average willingness to pay in each community, we gain a clearer understanding of the financial conditions that are necessary for heads of households to adopt the technology.

In both communities, we found strong support for an in-home water reuse system and a willingness to pay for many of the system's fixtures. Although the communities demonstrate an overall willingness to pay for the system, the opportunity to "renegotiate" and choose between fixtures also shows that different households have different desires and expectations. The communities were willing to pay different amounts, highlighting differences in community needs and desires for small water systems. Overall, the communities' willingness to pay for the in-home water reuse system demonstrates a motivation to improve existing sanitation conditions.

Accepted monthly costs varied between communities. The average accepted monthly costs across both communities was $74.48. This equals a monthly per capita cost of $39.77 in the Interior community and $21.44 in the YK Delta community. In the YK community, 43% of respondents were willing to pay for their initial monthly cost estimate (average of $81.44). The remaining respondents (53%) rejected their initial monthly cost estimate (average of $85.12) but agreed to their "renegotiated" monthly cost estimate (average of $54.97). In the Interior community, 27% of respondents accepted the first estimates (average $87.62). The remaining 64% of respondents rejected their initial cost estimate (average $166.92) and “renegotiated” to an average monthly cost estimate (average of $100.49). The average accepted cost was 40% lower than the first estimate but still higher than the average accepted cost in the first round.

The utility cooperative fee was unpopular in both communities. The AWSC guidelines provide only a broad overview of the cooperative. Respondents were told the cooperative fee would cover repair costs, but further details were not provided. Respondents expressed confusion and uncertainty about the benefits of the cooperative. Rural Alaskans must often rely on themselves and the tools they have on hand to perform repairs. Outside assistance is often delayed by weather, logistical challenges, and costs. Given these experiences, it may have been hard for respondents to visualize an effective cooperative worth the monthly charge. The monthly fee of $40 per month represents 54% of the average accepted monthly fee, which often excluded the cooperative fee.

In rural Alaska, the water-energy nexus is central to access to water and sanitation services. The adoption of the UAA prototype or maintaining the status quo each involves indirect energy costs. These may not be accounted for by respondents. For example, ice and rainwater were unanimously picked as the preferred water source for the prototype. In the YK Delta community, respondents indicated their choice was partially driven by a desire to avoid paying for bulk water at the washeteria, but hauling water requires fuel for the four-wheeler or human energy.[7] Direct energy costs are key determinants of the estimated monthly costs of the UAA prototype. Decreasing monthly costs hence required decreasing energy consumption. This may explain why the all-in-one washer/dryer combo, which was the most energy intensive prototype fixture, was one of the least popular fixtures. The survey responses highlighted that the washeterias will remain integral to communities even with in-home running water services. Washeterias are social hubs that facilitate community interactions and provide a backup if in-home systems break or become temporarily dysfunctional. Washeterias will also be necessary to supply water when rain or ice water is unavailable or when larger volumes of water are required.

There are several differences between the two communities. Interior community respondents were more willing to pay for shower fixtures. This may be due to the prevalence of steam baths in the YK Delta community and time-regulated showers at the Interior washeteria. Conversely, members of the Interior community were less inclined to pay for the urine-diverting dry toilet. This is likely because in the Interior, outhouses are commonly used and in the YK Delta, disposing of human waste requires traveling longer distances than in the Interior.

The communities had different fixture selection patterns. Respondents in the YK community tended to select all possible fixtures and then “renegotiate” to cut costs, while respondents in the Interior community were more selective during the initial monthly cost estimate. This may be explained by the fact that household size is smaller in the Interior community (average of 2.6) than in the YK community (average of 3.86), and many homes in the Interior community have less square footage overall, although the two communities may have similar footage per capita.

This study is unable to distinguish between the respondents’ willingness to pay and their ability to pay (affordability). In 2015, ADEC established the maximum monthly rate for AWSC systems at $135/month. The rate was set using an affordability metric that defined affordable rates as equal to or lower than 5% of a community’s median household income. The AWSC rate is equal to 5% of $2700, which represented a median household income lower than 75% of those of rural Alaskan communities,[30] but income varies significantly among rural Alaska communities. The AWSC monthly rate represented 4.6% of the median household income of the YK Delta community, but the fee accounted for 8.4% of the median household income in the Interior community, which is likely unaffordable.

Establishing and estimating respondent’s willingness to pay is essential for the viability and sustainability of water services. While ADEC will fund capital costs, users are responsible for covering the operations and maintenance costs.[30] In this study, respondents indicated a willingness to pay for the services, but the average accepted price was half of the suggested AWSC fee. The lower survey estimates are supported by ADEC’s new affordability framework. The framework estimates the maximum affordable fee for the YK Delta and Interior communities to be approximately $50/month and $30/month, respectively.[31] Neither of these estimates can account for personal preference or ability to pay.

Although this study determined respondents’ willingness to pay, the acceptable estimated monthly costs may vary. Rural households’ incomes vary during the year, as most cash-generating opportunities are seasonal. The communities were surveyed during the spring, when there are few seasonal jobs. Additionally, while this study differed from economic willingness-to-pay studies, some known limitations may apply. Respondents may overstate their willingness to pay for a fixture if it is perceived as giving prestige. It is also difficult to evaluate willingness to pay for unfamiliar products.[32] It is important to consider that other low-cost water and sanitation systems being developed in Alaska may better suit a portion or all of the community members that participated in this study. For example, the Alaska Native Tribal Health Consortium (ANTHC) led the development of a “portable alternative sanitation system” (PASS), that has been described previously.[15] PASS is intended to be an immediate improvement to sanitation conditions and complements existing water infrastructure in communities that have washeterias.[15] PASS includes a rain catchment feature, an indoor water storage tank, a bathroom sink, and a urine-diverting dry toilet with an optional urinal. The monthly operation and maintenance costs are estimated at $31.57. In comparison to the cost of our in-home reuse system discussed here, PASS may be more suitable for communities in which the average willingness to pay for an improved sanitation system is $50/month or less. The results from the YK community show that most respondents desire running water primarily for bathroom and kitchen sinks and the urine-diverting dry toilet. The PASS may more efficiently meet these wants.

The reuse system and findings of this study are relevant outside of Alaska. More than 1.7 million homes[33] in Arctic and remote regions of Russia,[34] Greenland,[35] and Canada[36,37] lack access to in-home water services partially because of the extremely high capital costs for centralized systems.[38] In these communities, funding an in-home reuse system could be more affordable than traditional systems. In the contiguous United States, high capital costs also hinder access to in-home water services in the Navajo Nation,[39] Appalachia region,[40,41] and

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ACS EST Water XXXX, XXX, XXX−XXX

the Colonias in Texas.[42] The COVID-19 pandemic has highlighted the disproportionate health impacts in Tribal communities throughout the United States owing to lack of access to in-home water services.[43] In 2019, 12.5% of Tribal homes[44] and 30% of the Navajo population[45] lacked access to in-home water services. The Indian Health Services estimates that connecting these unserved households would cost more than $2.6 billion. Hence, while representing a smaller percentage of the U.S. population, Tribal regions have the largest scope for improvement in water and sanitation infrastructure and associated environmental justice issues.

5. CONCLUSION

There are four key conclusions from this study. (1) Community desires for in-home water/sewer infrastructure may cost more than community members are willing or able to pay. System designers must carefully balance cost and health outcomes. (2) Regionally, there are differences in desires. On-site systems should be flexible to allow community members to select fixtures that suit their specific needs and ways of life. (3) Bathroom and kitchen sinks are the most desired fixtures. Although households tended to include showers and laundry machines during the initial cost estimate, they also tended to remove those fixtures during the "renegotiation". Bathroom and kitchen sinks should become a priority for currently unserved communities. (4) The process of engaging community members in discussions about willingness to pay was very important. This enabled the research team to better understand the specific wants and needs of these two communities.

Additionally, the survey of monthly costs used in this study could be adopted by engineers and project managers in rural Alaska and other rural locations to evaluate community readiness to upgrade from a self-haul system. Willingness to pay is a useful tool for bridging the gap between existing technology and community needs, allowing project managers and engineers to simultaneously analyze community desires with sanitation behaviors and to engage in necessary dialogue with community members.

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C.L.: methodology, investigation, data curation, writing of the original draft, and visualization. B.J.: reviewing and editing and visualization. E.H.S.: methodology, investigation, and review and editing. S.A.: data curation, review and editing, and visualization. A.D.: conceptualization, methodology, review and editing, funding acquisition, and project administration. All authors read and approved the final version of the manuscript.

Notes

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ACS EST Water XXXX, XXX, XXX−XXX