

Identifying the Built, Natural, and Social Factors of Successful and Failed Rural Alaskan Water Projects: Perspectives from State and Regional Professionals

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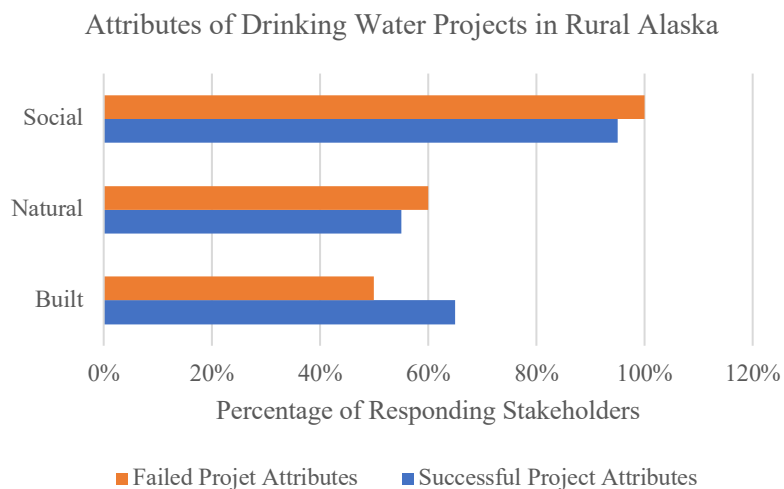
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ABSTRACT

Drinking water projects in rural Alaskan communities face a myriad of issues, often due to environmental challenges and financial constraints. These issues threaten community members' access to clean drinking water. Here, we report the built, natural, and social system factors that contribute to the failures and successes of rural water projects, based on 20 semi-structured interviews with engineers, program managers, service providers, and researchers whose work involves some element of water infrastructure in rural Alaska. Using a hybrid deductive and inductive approach to qualitative coding analysis, we aimed to uncover common themes in the perspectives of the individuals who maintain and operate drinking water projects to advance

understanding of rural water access. Interviewee responses indicate the significance of the interactions between built system factors (e.g., operations and maintenance), social (e.g., community engagement), and natural system factors (e.g., water quality) in determining the success of drinking water projects. Generally, the respondents agreed that design efforts that are rooted in the built and social systems (e.g., sociomaterial approaches) and that consider rural Alaskan communities' climate, geography, and cultures allow for effective implementation of sustainable drinking water projects.



KEYWORDS

Drinking water, rural water systems, water management, Alaska water

SYNOPSIS

This study explored the characteristics of successful and failed drinking water projects in rural Alaska to reveal the influence and interactions between built, natural, and social system factors.

1. INTRODUCTION

Household water insecurity is a critical problem affecting many remote Alaskan communities despite perceptions of water abundance in the state.¹⁻³ Household water insecurity is

defined as inadequate access to stable and affordable clean water in sufficient quality and quantity to maintain health and support livelihoods.⁴ Many scholars have documented household water insecurity in Alaska by focusing on inadequate *access* to water.^{5,6} Less documented topics include issues of water quality effect on household water security, water system operations in rural contexts, and individual choices around water.^{7,8}

Although many rural communities have access to a safe drinking water source, they are often impacted by various natural, built, and social system factors that affect the continued technical performance of the drinking water projects.^{9,10} For this analysis, we use the 2020 NSF definition of the natural system factors as the "atmospheric, biological, cryospheric, ecological, geological, hydrospheric and marine processes," the built system factors as "human-built physical infrastructure, telecommunications, cyberinfrastructure, and data systems and their interactions," and the social system factors as "human behavior and social organizations such as the economy, politics, and environment."¹¹ This definition generalizes the five dimensions of resilience that are commonly considered in resilience literature (i.e., built, economic, government, natural, social), where the social system factors encompass economic and governance system factors. Furthermore, this generalization is helpful within an engineering context where economic and government dimensions may not be referenced independently. For example, household water insecurity (i.e., social system factor) may be heightened due to the lack of piped water systems (i.e., built system factor) in specific underserved and unserved rural communities that use either a fee-based utility closed-haul water system or washeteria or central watering point respectively.^{12,13} Additionally, structural inequalities based on the legacy of American colonialism and domination have affected the governing and economies (i.e., social system factors) that currently support critical infrastructure (i.e., built system factors).¹⁴ Historical processes such as settler colonialism have

implications on both the physical loss of natural resources (i.e., natural system factor) and the drivers behind water stewardship (i.e., social system factor; e.g., viewing drinking water as a commodity without recognizing its social, cultural, and spiritual value).^{15,16} The establishment of permanent Alaska Native settlements, as compared to isolated villages, led to ongoing colonial processes of viewing water as something in need of human manipulation to purify and distribute the commodity of drinking water.^{2,17} As such, water insecurity is a product of current and historical natural, built, and social system factors.

Previous studies have observed the issue of water insecurity in rural Alaska through various vantage points. Several focused on the influence of water, sanitation, and hygiene (WASH) on drinking water projects and community health using analyses at the household and community level.^{5,18,19} For example, in the study completed by Mattos et al., researchers determined the technical and social factors that contributed to the success of household Portable Alternative Sanitation Systems (PASS) using collected qualitative data. The analysis determined that successful implementation of PASS and mid-tech WASH infrastructure is complex and dependent on the unique characteristics of the specific household.¹⁹ Similarly, other work focused on increased geogenic elements and pollution and their impacts on drinking water advisory levels and community health.^{20–22} One study examined climate change's exacerbation of environmental and community health.²³ The discussed ecological impacts contributed to evident and subtle health disparities disproportionately affecting Alaskan Native communities.

Other works have used frameworks to comprehensively analyze community drinking water in rural Alaska. For example, Williams et al. used the Arctic Water Resources Vulnerability Index to understand better how a community's adaptive capacity varies based on different ecologies and socio-economic systems.²⁴ Their study found that different communities on the same type of

topography maintain a similar ability to adapt biophysically and socially to changing environmental conditions. In recent work, Sohn et al. used casual loop diagrams to understand how stakeholders determined critical factors that impact household water vulnerability, resulting in five thematic models: economic, environmental, infrastructure, health, and social.³ The involved researchers explored economic and environmental sub-models, citing climate change and maintenance funding as notable challenges for rural Alaskan communities. Other studies closely examined how existing water projects are improved to combat environmental threats. For example, a study by McOliver et al. described four Alaska Native case studies to review how stakeholders have addressed pressing ecological issues with community-centered research.²⁵ As a whole, the existing literature has explored the threats to Alaskan water from various vantage points (e.g., WASH, technical system operation, environmental influences) using qualitative and quantitative means.

Although studies have continued to address household water security issues in rural Alaska, there have been calls to examine how the relationship between built, natural, and social system factors can influence planning and operations in the Arctic.¹¹ This call deviates from the existing literature as little of the existing work examines the perspectives of practitioners managing drinking water projects.³ Furthermore, it builds on the momentum of ongoing work that examines WASH-related issues from a systems perspective.²⁶ , this paper creates a conceptual model of the factors, interactions, and feedbacks that shape access to safe, reliable, and acceptable drinking water in rural Alaska using knowledge from individuals involved with the operation and management of drinking water projects at various vantage points. We aim to contribute to this body of work by reporting the perspectives of state and regional professionals involved in or familiar with the implementation, management, and oversight of rural water projects across rural

Alaska. To do so, we analyzed 20 semi-structured interviews with stakeholders across the state, including off-road communities in the southwest, southcentral, and southeast Alaskan regions to identify the natural, built, and social factors that define the success and failure of drinking water projects and systems in rural Alaska. Results of this analysis enables future transformative research by identifying research gaps and capacity needs and generating novel hypotheses about how this complex system responds to Arctic climate change.

2. MATERIALS AND METHODS

This research drew from 20 interviews with individuals working within tribal, federal and state agencies, private companies and firms, non-profit organizations, and academic institutions across Alaska that design, manage, and operate community drinking water projects. Given our respondent base, their experiences include a broad and representative range of rural Alaska drinking water projects built in recent decades, including federal and state-funded and volunteer projects. Here, we define a drinking water project as the process behind establishing access to drinking water, including the implementation of drinking water systems from planning and design to operation. We aimed to collect and disseminate knowledge from the perspectives of those who implement drinking water projects in rural Alaska. Specifically, the hybrid approach to qualitative analysis (i.e., deductive content analysis with subsequent inductive coding)²⁷ was used to determine vital attributes and trends associated with successful and failed drinking water projects, methods for treating groundwater and surface water, climate-related challenges that influence water treatment, and social equity and inclusion considerations within the context of rural Alaska. In doing this [what?], we seek to communicate these organizational stakeholders'

viewpoints rather than providing our own ideas as a form of co-creation of knowledge in drinking water project implementation.

2.1. DATA SOURCES AND COLLECTION

The interviewees were selected based on their experience with drinking water projects in the rural Alaskan context through a combination of convenience and snowball sampling. Interviewee selections were not dependent on demographic information nor an interviewee's specific role with Alaskan water projects (e.g., we did not choose to interview only water operators). Initial interviewee selections leveraged the research team's existing professional network, and subsequent interviews were sought following the interviewee's contact recommendations. The project proposal and sample interview questions were generated and approved by the Institutional Review Board at the University of Washington and the Alaska Area Institutional Review Board and reviewed by the Alaska Tribal Health Consortium Research Review Committee. Researchers distributed email invitations to potential interviewees requesting their participation, and interviews were completed through a combination of video conferencing (i.e., Zoom) and phone calls from October 2020 to April 2021. Each interview was approximately 60 minutes long, recorded with consent, and digitally transcribed before performing qualitative coding with the software MAXQDA.

The resulting interviews captured the professional knowledge of 20 employees representing 11 organizations within the design, development, operation, maintenance, water conservation, regulatory oversight, public health, and academic communities. Individuals' experience ranged from 10 to 42 years of involvement in rural Alaska communities' water resources and supply systems (i.e., applicable experience). The majority of the respondents did not reside in rural Alaskan communities. However, we believe that the chosen participants provided

unique perspectives considering their breadth of knowledge and experience in drinking water project implementation, management, and research. Additional information, including interviewee demographics, are included in supplemental information (SI).

Questions included in the interview were initially designed to generate thoughtful discussion about drinking water resources in rural Alaska with a specific focus on groundwater, however respondents spoke generally about all water sources. Interviewees were first asked to define the success and failure of rural Alaska water supply projects or systems based on their experiences. Further questions built upon unique factors in Alaskan water projects, including impacts of climate change, geographic conditions, and equity and inclusion considerations for communities. Using a semi-structured interview approach, we could include additional questions based on the respondents' responses.²⁸ The complete interview protocol can be viewed in SI.

2.2. QUALITATIVE ANALYSIS

Data analysis for this study involved qualitative coding of interview transcripts using the data analysis software MAXQDA. The qualitative coding process outlined and categorized segments of interest for each interview transcript and assimilated these coded segments with similar findings, ideas, and themes across the breadth of interviews. This analysis took an iterative approach to coding, revisiting interview transcripts, and recoding segments as new categories emerged (i.e., inductive qualitative analysis).^{27,29} While the research team used a list of questions to facilitate interviews, we did not use a predetermined list of coded categories to allow themes to emerge in the codes.²⁷

The excerpts were categorized into four categories: (1) successful project attributes, (2) failed project attributes, (3) defining factors of drinking water projects, and (4) advice and propositions. These parent codes were then analyzed and further segmented into the natural, built,

and social system factors defined by NSF (i.e., deductive qualitative analysis).^{11,27,30} Each system factor (i.e., project attribute) includes child codes that describe a specific factor (e.g., water quality, regulatory compliance). Additionally, system factors were coded as a successful or failed project attribute based on respondents' explicit definitions. A single researcher completed the coding, and a separate researcher assisted with the intercoder reliability check based on one excerpt (5% of the total). The coding was validated by a kappa value of 0.93, which is considered satisfactory in qualitative research³¹.

3. RESULTS AND DISCUSSION

The qualitative analysis revealed codes within the themes of built, natural, and social systems. The following tables report the emerging themes for successful and failed project attributes (Table 3) and advice and propositions (Table 4) categorized by built, natural, and social systems. The tables illustrate the relative frequencies (i.e., the proportion of responses in a category) for each parent code, including the number of coded excerpts. Figure 1 provides a visualization of the defining factors of drinking water projects; these themes are used in the text to contextualize discussions of codes in the tables. The following discussion examines the most prominent built, natural, and social system factors of each parent code and generates theories on how interactions between the factors may influence the success and failure of drinking water projects. Generally, the themes that arose in the qualitative analysis reflect similar concepts and add to the discourse described in the existing literature.^{3,19}

Table 3. Frequency Table for Successful and Failed Project Attributes

<i>Qualitative Code</i>	<i>Successful Project Attributes</i>		<i>Failed Project Attributes</i>	
	<i>Number of Interviewees</i>	<i>Number of Responses (Relative Frequency)</i>	<i>Number of Interviewees</i>	<i>Number of Responses (Relative Frequency)</i>
<i>Project Attributes</i>	20	115 (100.0%)	20	188 (100.0%)
Built System	13	25 (21.7%)	10	16 (8.5%)

Operation, maintenance, and resilience	10	20 (17.4%)	10	16 (8.5%)
Water treatment scheme	3	5 (4.3%)	0	0 (0.0%)
Natural System	11	24 (20.9%)	12	32 (17.0%)
Water quality	5	7 (6.1%)	4	6 (3.2%)
Water resources (e.g., availability)	11	17 (14.8%)	5	5 (2.7%)
Climate and terrain	0	0 (0.0%)	5	9 (4.8%)
Geographic remoteness	0	0 (0.0%)	6	12 (6.4%)
Social System	19	66 (57.4%)	20	140 (74.5%)
Experienced and trained personnel	8	12 (10.4%)	16	40 (21.3%)
Health outcomes	3	3 (2.6%)	0	0 (0.0%)
Regulatory compliance	5	7 (6.1%)	0	0 (0.0%)
Finances	7	11 (9.6%)	18	51 (27.1%)
Community affordability	6	7 (6.1%)	13	32 (17.0%)
Economic stimulus to the community	4	4 (3.5%)	0	0 (0.0%)
Financial management	0	0 (0.0%)	6	7 (3.7%)
Wages for employees	0	0 (0.0%)	8	12 (6.4%)
Community engagement	15	33 (28.7%)	17	49 (26.1%)
Community buy-in	15	24 (20.9%)	11	14 (7.4%)
Water resource education	6	9 (7.8%)	0	0 (0.0%)
Cultural complexities	0	0 (0.0%)	15	34 (18.1%)
Community expectations	0	0 (0.0%)	1	1 (0.5%)

Table 4: Frequency Table for Advice and Propositions

<i>Qualitative Code</i>	<i>Number of Interviewees</i>	<i>Number of Responses (Relative Frequency)</i>
Advice and Propositions	20	89 (100.0%)
Propositions	18	54 (60.7%)
Social System	15	30 (33.7%)
Financial	8	14 (15.7%)
Education and training	10	13 (14.6%)
Regulations and practice	1	2 (2.2%)
Personnel	1	1 (1.1%)
Built System	13	26 (29.2%)
Improved transportation	1	1 (1.1%)
Water system technologies	12	24 (27.0%)
Advice for Outside Organizations	19	35 (39.3%)
Social system	19	35 (39.3%)
Community engagement and understanding	12	20 (22.5%)
Finances	4	4 (4.5%)
Logistics in Alaska	9	11 (12.4%)

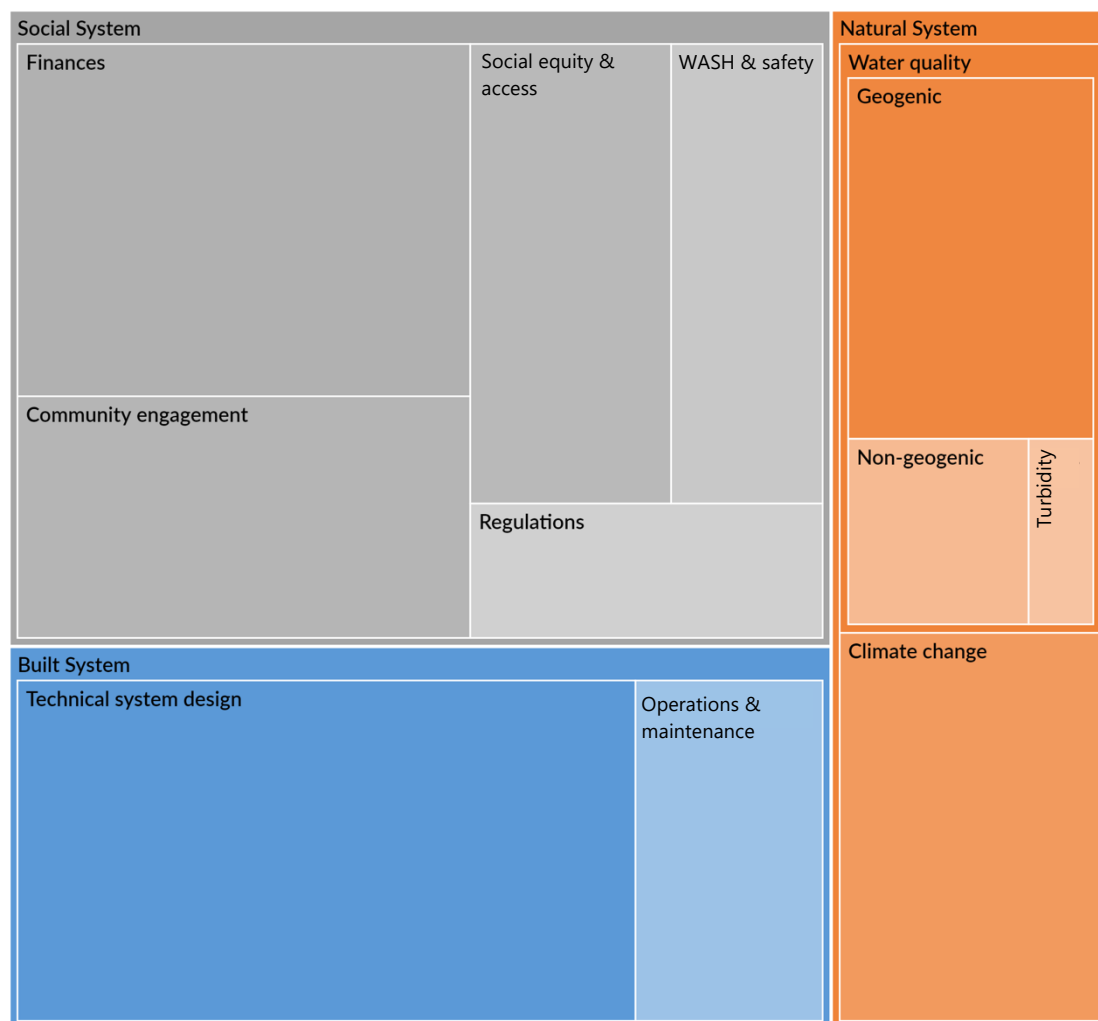


Figure 1: Hierarchy chart of the defining factors of drinking water projects. The intensity of color correlates to number of items coded to the factor. The size of the areas refers to the number of coding references (i.e., relative frequency).

3.1. SUCCESSFUL PROJECT ATTRIBUTES

While respondents were tasked with determining definitions of success and failure based on their own experiences, they generally categorized successful drinking projects with well-maintained technical systems, access to natural resources, and adequate community engagement. More than half of the respondents (13; 65% of the total) described built system factors when describing the success of drinking water projects. Specifically, 10 (50% of the total) respondents described an aspect of the project's technical system's operations, maintenance, and resilience. For

example, several interviewees mentioned the need to stockpile necessary materials, keep up to date with preventative maintenance, and adhere to a standard operation procedure. One respondent described the benefits of uniformity in one remote area, "[the region has] 20 communities that all use the same parts... it's much easier to get [materials] when you're not the only one with something unique and in that place." Although there may be barriers to standardizing drinking water technical systems across a region, standardization could provide benefits for improving drinking project performance (i.e., built system factor) and water operator education and retention (i.e., social system factor), thus increasing the success of a drinking water project in the state.³²

Other interviewees noted the necessity of maintaining and creating simple water systems whose operations can quickly be passed down along multiple generations of water system operators or stakeholders, allowing for a more sustainable and robust water system. This sentiment echoed the discussion of resilience and sustainability for drinking water projects. For instance, one respondent described "a system that can last 20 years with bare-bones maintenance" as a characteristic of a resilient and successful drinking water project. Interviewees described sustainability as the prolonged use of a water system that could be supported by an improved technical system, a more significant financial capability, and adherence to the intended design and operation, which demonstrates the interaction between built and social system factors. Drinking water systems' operation, maintenance, and design (i.e., built system factors) that are unique to the climate and topography of rural Alaskan communities (i.e., natural system factors) may improve the resilience and success of a drinking water project. For example, three respondents (15% of the total) mentioned that a drinking water project's water treatment scheme contributes to success. While the water treatment level depends on natural system factors (e.g., turbidity, geogenic elements), a drinking water project's water treatment scheme could be manageable and

235 affordable for a community while meeting treatment requirements.¹⁹ Generally, the interviewed
236 stakeholders agreed that alternative and simplified techniques such as mid-tech water
237 infrastructure should be implemented for rural Alaskan water projects to ensure communities have
238 access to a clean and sustainable drinking water supply.

239 Beyond the built system, drinking water projects in rural Alaska are highly dependent on
240 water resources (i.e., natural system factors). Half of the respondents highlighted the importance
241 of existing water resources in successful drinking water projects. As approximately 75% of all
242 freshwater in the state is stored in glacial ice, access and proximity to water resources would ensure
243 that rural communities have the foundation needed for sustainable and uninterrupted water
244 service.²⁴ For example, one interviewee described the added benefit of having a water source that
245 is close to a community reduces the need to pipe and heat the water (i.e., built system factors),
246 which could affect operational costs (i.e., social system factor) and water quality (i.e., natural
247 system factor). Specifically, five respondents (25% of the total) highlighted water quality as a
248 successful drinking water project component. However, one respondent described that for drinking
249 water projects in the state, “adequate yield... or usable quality yield is rarely the issue,” suggesting
250 more significant concerns in other system factors.

251 Nearly all respondents (19; 95% of total) highlighted social system factors when discussing
252 successful drinking water projects. Community engagement was the category most often described
253 as a contributing factor to successful drinking water projects (15 respondents; 75% of the total)
254 and was mentioned to be especially important for remote water systems where the early
255 involvement of the local community can ensure that residents understand the value of investing in
256 properly regulated systems. In rural Alaskan communities, engagement may refer to community-
257 led or non-community-led initiatives (e.g., programs hosted by researchers or engineers) that take

a human-centered design approach to educating and informing decisions on drinking water project implementation by demonstrating involvement in the community.^{33,34} One respondent, a researcher with expertise in water treatment, expanded on this sentiment:

"I think the communities that we've had the greatest success kind of digging into these subjects are the ones where, before we ask anyone a single question, we spend four days in the community, not doing anything other than saying hello... If you think it's going to take two days to do the work, spend five times that amount of time out there... And if it's at all possible, leave something with the community so that they believe you helped on their needs... even if it's extraneous to your project."

Communities' perception of investment into water systems depends on water resource education, which was determined to be an attribute of successful water projects by six (30%) interviewees. Bidirectional educational programs promote knowledge sharing and effective resource allocation for project planning and development, similar to the participatory rural appraisal approach used for rural development.³⁵ Furthermore, it presents an opportunity to build trust between community members and other water resource stakeholders that may be entering the community.³⁶ However, these programs can often be constrained by limitations to the available workforce and budget.

Less frequently discussed social system factors that promote success in drinking water projects included experienced and trained personnel (8 respondents; 40% of the total), regulatory compliance (5 respondents; 25% of the total), health outcomes (3 respondents; 15% of the total), and finances (7 respondents; 35% of the total). Generally, a successful drinking water project

requires the resources (e.g., finances, personnel) to satisfy water quality standards (e.g., regulations) and maintain the community's public health.

3.2. FAILED PROJECT ATTRIBUTES

Interview respondents broadly described failed drinking projects as initiatives that could not fulfill the mission of supplying quality water to communities due to mismanagement, lack of understanding, or other complications. Compared to the discussion of successful project attributes, fewer interview respondents discussed built system factors as critical contributors to failed drinking water projects. While none mentioned the water treatment scheme, half of the respondents addressed potential shortcomings due to operation, maintenance, and resilience. One interviewee referenced the social system factors' influence on the built system, mentioning the difficulty behind generating revenue to keep a water system in operation. As one interviewee described, scenarios like this often led to situations where "the operator and the community give it their best to keep the system running, and the system [would] usually stay running until something catastrophic happens" due to the lack of proper maintenance. Shortcomings within built system factors, further impacted by social and natural system factors, have led to troubling issues influencing communities' access to clean drinking water, as demonstrated by the American Society of Civil Engineers "D" rating for drinking water infrastructure in Alaska.⁴¹ Like successful drinking water projects, the interactions between the different system factors can contribute to apparent failure.

Natural system factors were discussed by 13 respondents (65% of the total) in the context of failed projects and included climate, terrain, geographic remoteness, and water resources and quality. For example, one of the five interviewees that described water resources mentioned that the communities they interact with must use surface water sources that freeze during a significant

part of the year in areas with insufficient groundwater sources. These communities are forced to make water, which involves drawing from a raw water source before treating and storing it in tanks for the colder months. Community water insecurity would increase if surface water sources similarly deplete, as they are in many places due to climate change-induced melting permafrost. Another respondent described the difficulty a remote community experienced due to alternating water availability and demand based on seasons. The community members often let the water run to combat frozen pipes in the winter, rapidly depleting the quantity of stored water. In previous winters, the community has used an alternate water source, the Yukon River, which was reported to be “just full of silt.”

Furthermore, the use of available water resources could be affected by water quality, given the amount of geogenic elements naturally found in groundwater, for example. While only four respondents (20% of the total) described water quality as a contributing factor to project failure, 19 respondents (95% of the total) described water quality as a defining factor due to the various water treatment issues needed to control naturally occurring elements. One interviewee discussed seeing an arsenic level as high as 7000 parts per billion in one well, much higher than the Environmental Protection Agency's (EPA) standard of 10 parts per billion.³⁷ This discovery caused issues for the specific community in drilling a new groundwater well nearby.

Other respondents described how geographic location differences could affect what type of element is more likely to cause complications for the water system. For example, iron poses more of an issue for Southwest Alaska than arsenic. Iron, a secondary contaminant that causes aesthetic and technical effects to the water and physical pipe system, respectively, does not receive the highest funding considerations as compared to arsenic, a primary contaminant that can cause health complications. However, the naturally occurring secondary contaminant can cause build-up

in pipes and wells. Alternatively, several respondents discussed other water quality factors that affect water systems, including non-geogenic elements and turbidity. Discussed issues included changes in water chemistry due to increases in organics, saltwater intrusion, and more significant storm events that impact turbidity. For instance, one respondent detailed the variability in water quality due to weather in a water system where "the organic carbon varied from maybe two to three milligrams per liter to 10 to 12 milligrams per liter... and you had some variations and turbidity... [when it was sunny] you had one quality water and [when there was a storm] we had another quality water." These additional factors contribute to the overall challenge of enacting effective treatment processes for the natural system.

Five respondents (25% of the total) described climate and terrain as contributing to the failure of drinking water projects, especially highlighting ground conditions that can influence built system factors. Communities along the coast face challenges caused by the increasingly visible effects of climate change (e.g., widening rivers and eroding shorelines). Furthermore, technical systems (i.e., built system factor) that were put in place under previous considerations for climate and terrain may not be able to withstand impacts due to rising temperatures and other shifts in the environment. For example, one interviewee mentioned witnessing "a lot more pipe breakage" due to the thawing of the permafrost older water systems may have built on in communities above the Arctic Circle. Beyond infrastructure breakage, permafrost thaw can also lead to continued turbidity and erosion and reduced groundwater quality, especially in the 30% of Alaska that has continuous permafrost.³⁸ While there may be temporary solutions to this issue, this [what?] does not aid the rest of the distribution system, which could be subjected to differential movement.

Moreover, six respondents (30% of the total) mentioned the effect of communities' remoteness as a contributor to the failure of drinking water projects. As 86% of Alaskan communities are not connected to a road system, rural communities have the additional difficulty of receiving assistance to manage drinking water projects.³⁹ Scenarios like this exemplify the necessity of considering the interactions between the different system factors to solve impending threats to water security in the region.

Similar to the discussion of successful project attributes, most references to failed drinking water projects were of factors within the social system (100% of respondents). Notably, 18 respondents (90% of the total) described finances as a contributing factor to failure, with community affordability, financial management, and employee wages being discussed the most. One respondent with a background in engineering for rural water systems identified how financial capabilities impact the overall lifespan of rural water systems in a specific region:

"Very few small water utilities here have any kind of capital, they don't have any [means] to borrow money or bond or any of these features, and generally the cost of improvements or even major repairs are far beyond anything that they're capable of doing on their own... Over time, performance generally degrades substantially, and that usually means for quality water and higher cost to the consumers."

Interviewees discussed that government subsidies, capital investment, and other programs in water supply projects would open doorways for improving local water infrastructure jobs, revenue, and opportunities with O&M support activities. While such initiatives have been implemented (e.g., programs through the Denali Commission and the Alaska Sewer and Water

Challenge), many communities are still threatened by water insecurity and often lack the financial means to aid themselves.^{34,40} For example, several interviewees described a point system used by the state government to determine what projects may be awarded financial support. However, communities would need to demonstrate “that they’re going to protect that investment” leading to funding awards given to communities with history of water project success rather than the communities that actively need the support. Situations like this widen the gap between rural water systems and can intensify already existing issues involving social equity and access.⁴¹

Other interviewees noted how social system factors interact with natural and built system factors related to the payment of operators: the minimized value of water system laborers and reduced financial capability of a community can negatively impact the number of hours and pay available for operators. According to several interviewees, this interaction results in difficulty with workforce retention and personnel that may not be able to manage water quality and environmental concerns (i.e., natural system factors), leading to an unmaintained water system (i.e., built system factor). A lack of certified operators is an issue for many small and rural communities across the United States.⁴² A combination of the remoteness of rural Alaskan communities and the lack of competitive pay in the water management sector further contributes to maintaining long-lasting drinking water systems.

Although not explicitly described when asked about the failed attributes of drinking water projects, we theorize that meeting the EPA’s water quality standards can pose challenges to drinking water projects. One interviewee detailed that the “one-size fits all” approach for regulating surface water and groundwater (e.g., requiring different regulations depending on the elevation of the water source) wastes a considerable amount of funds that could go to O&M. Similarly, another respondent described cases where groundwater may be connected to a spring that rises to the

surface in a separate location. Although the same water may pass through this system, "the government deems it necessary to put sand filters, treatment, and everything else on it, even though the water surfacing is good." Not only would this scenario put a financial burden on water providers due to the additional treatment measures, but community members may prefer other water sources over the heavily treated water due to its additives. While several respondents highlighted the importance of these water standards in providing clean water to communities, they also recognized that general regulations might not consider the unique topography, water chemistry, and cultural considerations found in rural Alaska compared to the continental United States.

As described by 17 respondents (85% of the total), a lack of community engagement can lead to failure in a drinking water project with ample funding and access to water resources. Community engagement often depends on a drinking water project's acknowledgment of local culture and traditions; 15 respondents (75% of the total) described cultural complexities as an attribute of failed water projects. One interviewee cited the "skepticism around chemical treatment practices" as a reason behind the preference for traditional water sources and thus leading to the failure of drinking water projects focused strictly on water treatment. The hydro-social cycle in many rural Alaskan communities follows their respective Indigenous traditions that value and interact with water resources differently from larger and more urban communities.^{16,43} Drinking water projects implemented without solid community buy-in could fail by not considering the cultural knowledge that develops from a community's traditional relationship with water.

3.3. PROPOSITIONS

As described by interview respondents, there are factors that stakeholders involved with drinking water project implementation can focus on to ensure the success of drinking water projects in rural Alaska. While some system factors may be unchangeable at the project management scale (e.g., permafrost in a specific region), considering the interactions between built and social system factors may help reduce household water insecurity in the state. Here, we identify the implications of this analysis and aim to effectively communicate the respondents' actionable propositions (Table 4) for policy or aid in rural Alaskan water projects. Broadly, the coded interview excerpts in this analysis agree with the findings of previous studies that uncover the limitations of water system success as geographic remoteness, water quality, and financial affordability^{3,25,43}. However, this work also reveals how the interactions between system factors can contribute to a drinking water project's level of success. Such interactions can be seen within discussions of climate (i.e., natural system factor) and how that may influence the design of a technical system (i.e., built system factor) or how a lack of community engagement (i.e., social system factor) can lead to an unused and unmaintained water system (i.e., built system factor).

Based on the experiences described by interview respondents, many of the discussed project attributes could directly influence or be influenced by built system factors. For example, all built system factors (i.e., operation, maintenance, and resilience and water treatment scheme) have a significant relationship with each natural and social system factor. This same relationship is not seen between other system factors (e.g., climate and terrain do not directly affect wages for employees and vice versa), suggesting the critical role and influence that the built system has on the implementation of drinking water projects. As such, this realization can better inform the ideation of techniques and actions to improve the more readily adaptable system factors (i.e., built and social) to reduce household water insecurity by enabling approaches rooted in

sociomateriality. Here, we refer to sociomateriality as a reference to the space in which “social and material agencies” overlap to produce technologies and organizations, respectively.⁴⁴

Of the respondents (18; 90% of the total) that described ongoing and future approaches for aiding drinking water projects in rural Alaskan communities, more than half of the respondents (65% of the total) highlighted the built system factors. As climate change impacts water availability and existing technical systems, stakeholders at different levels recognize the various developments necessary for the built system. For example, several respondents discussed the continued need to create and use technologies unique to rural Alaskan regions' natural and cultural environment (e.g., alternate and affordable filtration techniques, solar panels for energy during summer months). One respondent detailed a method of operating the technical system in a way best fitting for the community:

"The system needed to be able to operate unmanned... so I came up with this idea of using upstreaming and the current detector to track the net charge density of the water using charge neutralization as the primary means of coagulation... that was one means of being able to [empower] the community to be able to control the system."

However, while describing the benefits of technological innovation, one interviewee stated, "... you have one trip up with automation, and nobody can fix it... There's a fine line or a delicate balance between levels of automation, the levels of manual control that you want to provide for systems like that." Although digitalization and automation have increased in urban water systems,⁴⁵ technological innovations in the rural Alaskan context should consider the community's needs and overall resiliency before being implemented. Beyond technology needed

for water infrastructure, improvements to transportation infrastructure may assist in getting rural systems more connected for supply chain and aid. One interviewee suggested that improving transportation infrastructure, similar to rural communities in Nordic countries, would reduce the issues caused by geographic remoteness. In more remote areas of Alaska, the geographic remoteness lowers the reliability of a water supply due to location and heightened transportation costs.⁴⁶ Similarly, increased connectivity can assist in the transfer of resources between communities, which has previously been found to help rural water systems in the continental United States during emergencies such as the COVID-19 pandemic.⁴⁷

However, the interviewees additionally recognized the financial need (i.e., social system factor) required for an improved built system. Eight (40%) interviewees identified the benefit of government subsidies, specifically for water costs and operator pay. As 90% of respondents described finances as an attribute of a failed water project source, "a revenue source to help fund the utilities" would be the most "desperately needed thing" for water systems, as described by one interviewee. Tribal nations across the United States experience funding limitations and may depend on federal grant programs to improve technical systems.⁴⁸ In addition to finances, 50% of the interviewees suggested other interventions for the social system through education and training programs. For example, one interviewee described working with community members on the implementation of the water systems:

"... We'd send in one or two or maybe three very qualified people, depending on the type of work that we're doing. And then we hire the majority of the labor from the village and will train them... When we do projects' force account' to build local capacity to integrate

sustainability into our systems, so people understand how they're built, they can fix it themselves."

These initiatives, which may be supported through ongoing government subsidies or organizational aid, would assist in improving community buy-in for drinking water projects. As a result, this [what?] would improve the O&M needed to sustain water systems. For example, the North Slope Borough and other borough governments subsidize local water and sewer systems which help keep rates and O&M costs affordable.⁴⁹

Furthermore, 95% of interviewees provided insights for outside organizations (e.g., organizations from the continental United States or abroad or organizations unfamiliar with rural Alaska) that want to improve drinking water systems in rural Alaska. All suggestions were related to the social system; respondents recommended that organizations and government entities outside of Alaska be aware of the difference in cultures and the necessity for community engagement. Similarly, one interviewee highlighted the need for patience and communication, especially when drilling to find a water source:

"Too many times where [looking for water by drilling] went wrong where there were tons of money waste and results were minimal. And so, a lot of the time it's just thinking if they just went out and asked [local] people about where they might go and do this, that it might be a little bit better done."

Generally, interviewees agree that outside organizations must recognize the uniqueness of Alaska and the specific rural community and actively use a human-centered approach to assist in

developing any water system project. To improve built system factors, social system factors should be carefully considered to ensure that a community's autonomy is respected while adequate access to clean drinking water is provided. Overall, approaches to drinking water project implementation that understand the interactions between the system factors can help reduce household water insecurity in rural Alaska.

4. LIMITATIONS

Although this study represents a subset of a larger population, we consider these generalizations an applicable and valuable representation of technical stakeholder input for rural Alaska community water supply projects and systems. By using a systemic coding approach, the research team ensured that the emerging information in the study could be adequately used to draw conclusions and determine potential interventions. Additionally, the line of questioning used in interviews specifically included questions about groundwater. Although this inclusion did not prevent respondents from speaking generally about both surface and ground water, the questions may have influenced resulting responses. Separately, variations may exist even between water supply projects in the same region as each project has unique facets in scope, site conditions, and community expectations. This study aims to draw out broad themes and factors that will assist future rural Alaska water resource development with varying characteristics. Furthermore, the frequency of coded segments and the number of respondents may not directly represent the significance of a factor or theme for water supply projects and systems. Consideration should be given that higher or lower frequencies may be attributed to the level of the interviewee's awareness of each factor or idea presented. The results indicate that some aspects are more pervasive or deeply rooted within the known sphere of rural water supply projects than others.

531 This paper reports the perspectives of individuals with occupations that involve rural water
532 systems, most of whom do not reside in the communities where they work on projects. One major
533 limitation of this paper is that only one interviewee (5% of the sample) identified with the Alaska
534 Native/American Indian demographic in our survey, while the racial background comprises 15%
535 of the total Alaskan population.⁵⁰ This limitation is mostly due to the demographic make-up of
536 those involved in drinking water system projects and disruptions caused by the COVID-19
537 pandemic, including regional and community travel restrictions and stay-in-place mandates. Our
538 results therefore reflect the perspectives of a different population: individuals involved in water
539 systems projects and maintenance but not the direct consumers of that water. In acknowledgment
540 of the respondents' backgrounds, these results should be interpreted as the viewpoints of
541 individuals involved with the implementation, structural management, and oversight of rural
542 Alaskan drinking water projects. As such, discussions involving governance, a subset of social
543 system factors, revolved mostly around regulations. We speculate that if our sample pool included
544 more Alaskan natives, there could have been more discussion of social system factors, especially
545 related to cultural considerations, history, governance, and community autonomy.

546 The second phase of this study addresses this limitation by centering on direct community
547 engagement, through which we will supplement the dataset by providing direct testament from
548 water system users. Future in-person community outreach and engagement are planned for the
549 next phase of this study as restrictions limiting access to rural Alaskan Indigenous communities
550 are lifted, and adherence to maintaining local public health is met. Including community members
551 in the research plan will provide a perspective necessary to more fully comprehend the success
552 and failure of rural Alaskan water projects. However, we believe this preliminary study may begin
553 to provide insights into critical areas of concern shared by interviewee respondents statewide

related to water supply projects and potential mitigation strategies. Given the large influx of federal funding allocated to Alaska for water and sanitation projects, understanding concerns on these different levels of positionality (e.g., state-level managers, community-level managers, developers, researchers, and consumers) will be of vital importance.

CRedit AUTHOR STATEMENT

Nathalie Thelemaque: Writing – Original Draft, Writing – Review & Editing. **Andrew Cotherman:** Formal analysis. **Rachel Pearson:** Formal analysis. **Laura Eichelberger:** Conceptualization, Resources, Writing – Review & Editing. **Rebecca B. Neumann:** Conceptualization, Investigation, Writing – Review & Editing. **Jessica Kaminsky:** Conceptualization, Investigation, Writing – Review & Editing.

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