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WATER, SANITATION, POLLUTION AND HEALTH IN THE ARCTIC

The search for an alternative to piped water and sewer systems in the Alaskan Arctic

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Abstract Forty-two communities in rural Alaska are considered unserved or underserved with water and sewer infrastructure. Many challenges exist to provide centralized piped water and sewer infrastructure to the homes, and they are exacerbated by decreasing capital funding. Unserved communities in rural Alaska experience higher rates of disease, supporting the recommendation that sanitation infrastructure should be provided. Organizations are pursuing alternative solutions to conventional piped water and sewer in order to maximize water use and reuse for public health. This paper reviews initiatives led by the State of Alaska, the Alaska Native Tribal Health Consortium, and the Yukon Kuskokwim Health Corporation to identify and develop potential long-term solutions appropriate and acceptable to rural communities. Future developments will likely evolve based on the lessons learned from the initiatives. Recommendations include Alaska-specific research needs, increased end-user participation in the design process, and integrated monitoring, evaluation, and information dissemination in future efforts.

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Overview: the state of water and sanitation in rural Alaska

The state of Alaska is 1,723,337 km^2 in area (U.S. Census Bureau 2010) and home to approximately 740,000 people (United State Census 2015). About 10% of the population lives in 185 remote communities scattered across the state each with less than 1100 people (B. Griffith, presentation, Water and sanitation summary for Alaska, Water Innovations for Healthy Arctic Homes Conference (WIHAH) 2016). These communities and people represent "rural Alaska" in this paper.

Communities in rural Alaska experience three different levels of water service. A served community is one where the majority of homes have piped water and sewer service. An underserved community is one that maintains a fee-based utility closed-haul water and sewer system where water is hauled to the home and sewage is hauled away from the home. An unserved community is defined as one where less than 55% of the homes are served and community members are self-reliant on a central watering point or a community "washeteria" with laundry and showering facilities. Household-based sanitation such as a 5-gal bucket, referred to as the honey bucket or private pit latrines for a toilet and a handwashing basin, are commonly used. Of the 185 rural Alaskan communities, the majority are considered served. Those considered unserved or underserved are 31 and 11 communities, respectively (B. Griffith, presentation, Water and sanitation summary for Alaska, WIHAH 2016). The majority of the unserved communities are located in the Yukon Kuskokwim Delta region of the state.

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Challenges to providing clean water and sanitation to the home

Providing water and sewer service to the homes in rural Alaska is challenging. Communities are geographically isolated, where most are accessible only by air and some seasonally by barge. Most residents of these communities are subsistence hunters and gatherers; there are few employment opportunities. The harsh environment makes building and maintaining systems more complex and expensive due to high costs of shipping materials, construction, and energy. Training and maintaining a certified operator to ensure public and environmental health is a struggle due to a limited work force to draw from and a workload that is often less than a full-time position, limiting the earning potential and thus the incentive to train and then remain in a job with a high responsibility but limited pay. Additionally, communities in rural Alaska are subject to climate change; many communities in rural Alaska are experiencing warming temperatures, thawing foundation soils (permafrost), increased flooding/storm surge, and other climate phenomena that put existing and new infrastructures at risk. The villages that remain unserved or underserved are either the most remote or located in geographically challenging locations or have not been able to demonstrate capacity to operate and maintain a functional system. This can be a daunting task for communities with limited resources, where economic challenges continue after the installation of water and sewer infrastructure.

In addition to being the most challenging to serve, implementation costs per home served are expected to be the most expensive to date for those communities that currently lack service. Capital funds needed to build water and sewer infrastructure are provided by federal and state grants. Both funding sources have dropped drastically in recent years, resulting in over US$2 billion of unmet need (B. Griffith, presentation, Water and sanitation summary for Alaska, WIHAH 2016). The cost of installing new systems is coupled with an increasing need for costly critical repairs or upgrades in rural communities with aging water and sewer infrastructure across the state.

The health consequences in unserved communities

In unserved rural Alaska, high rates of disease have been observed. The World Health Organization states that for a low level of health concern, a person needs an average of 50 l per capita per day (l/c/d) (13.2 gal per capita per day or g/c/d) accessible through a tap on their home plot where a total collection time is less than 5 min (Howard and Bartram 2003). According to the report, this arrangement assures that consumption, personal and food hygiene, and laundry and bathing are possible. Hunter et al. lists six factors key to whether or not water supply can effectively maintain good health (2010). They include the following:

- Quality of the water related to pathogens and chemicals
- Quantity of water available for use
- Access to water, determined by either physical distance or socioeconomic status
- Reliability of the water supply
- Cost of the water
- Ease of management of the water supply

Recent studies have shown a relationship between water use and health in rural Alaska. Thomas et al. found that four communities transitioning from an unserved state to a served state, piped water available in the home, experienced significant declines in respiratory, skin, and gastrointestinal infections (2016). Those health improvements were coupled with increased water use from an average of 5.7 l/c/d (1.5 g/c/d) in unserved homes to 97.3 l/c/d (25.7 g/c/d) in served homes (Thomas et al. 2016). These findings support the earlier ecological associations found by Hennessy et al. demonstrating higher respiratory and skin infections rates in regions and villages with a high proportion of unserved homes and support the recommendation that the disparity should be addressed through sanitation infrastructure improvements (2008).

Observed in-home water practices in unserved communities

Due to the low volume of water brought into homes in these unserved communities, water use practices vary from those of plumbed systems. In particular, home occupants often reuse water directly for the same purpose (i.e., multiple handwashings in the same basin of water) or uses involve less human contact (i.e., handwashing basin water to mop floor). While these practices extend the usability of each gallon of water (i.e., 1 gal of water may achieve 1.5 gal worth of use), the homeowner is accepting (acknowledged or not) the potential increased risk associated with reuse. The added benefit of this type of reuse and, conversely, the increased adverse health risk by activity is not easily identified and quantified. Through understanding of these practices and the acceptability and necessity of reusing water, engineers and social scientists have been able to more freely discuss alternative options to conventional piped water and wastewater systems.

Trends and likely future developments

Organizations have started looking for alternative solutions to provide water and sewer infrastructure to maximize water use and reuse in order to obtain the greatest public health benefit in 31 unserved and 11 underserved communities. Additionally, existing infrastructure in served communities may be impacted by climate change and other factors in the future; the U.S. Army Corps of Engineers has designated 160 rural Alaska communities as threatened by erosion, with three having already begun relocation plans (State of Alaska n.d.-a). Three initiatives across the state are working to develop solutions to these familiar but growing problems.

Though the technologies and processes differ, similarities exist in the three approaches taken by the State of Alaska, the Alaska Native Tribal Health Consortium, and the Yukon Kuskokwim Health Corporation (described below and summarized in Table 1). All of the initiatives rely on multidisciplinary skills that include social science as well as engineering expertise, while also engaging the end-users' perspectives which are critical during the entire process. These similar aspects are targeted at ensuring that developments are appropriate and acceptable for rural Alaskan communities and potentially providing long-term solutions.

Current initiatives

Alaska Water and Sewer challenge

The Alaska Water and Sewer Challenge is a state-led research and development project focused on developing household water reuse technologies to provide in-home water and sewer at significantly reduced capital and operating costs when compared to piped infrastructure. The project is comprised of five phases spanning from the fall of 2013 to 2020 and beyond. Three teams are currently participating in Phase III: Prototype Development and Pilot Testing. Results of the initial testing will be presented to the Steering Committee, and systems that demonstrate promising results at the end of 2017 will move on to Phase IV: Field System Development and Testing.

A short description of the three teams and the key components they identify for their systems are as follows: Per the criteria set out by the State, systems proposed by the following teams are to cost no more than US$160,000 capital cost and US$135 per month inclusive of a US$40 per month cooperative fee. Note that the described capital cost assumes a community watering point or washeteria is available and that the community has a functional wastewater haul system. Use of these facilities is included in the allowable monthly cost (such as homeowner self-haul of purchased drinking water and community-paid haul of home-produced wastewater). Accurate costs per system are unavailable at the time of this writing due to design modifications during this phase of the Challenge. The State provided additional criteria requiring that the systems provide 15 g/c/d for a total amount of 420 gal for a household of four per week.

University of Alaska Anchorage The University of Alaska Anchorage heads a team of academics, engineers, and health professionals. At the 2016 WIHAH conference, this team presented their most recent work focused on developing household water reuse technologies. UAA's system, as designed, could serve multiple homes with minor modification (i.e., tank sizes). The system consists of three subsystems, a drinking water system, a toilet, and a wash water system. The drinking water system and toilet are located within the home and do not greatly diverge from the existing practice in many communities. The wash water system is currently located in an insulated structure built from a metal shipping container located next to the home and connected via an insulated conduit. These systems are briefly described:

> *Drinking water*: Water that is collected from a public watering point is brought to the home, filtered through a 1-μ cartridge filter and disinfected using ultraviolet light before being made available through a spigot located at the kitchen sink and bathroom sink. Drinking water treatment is intended only to provide pathogen reduction in case of contamination during transport from the public watering point to the home. The provided treatment system does not provide adequate treatment to produce water quality to meet primary drinking water standards from raw water sources (i.e., surface water or rainwater) with unknown contaminants.
>
> *Toilet*: A dry urine-diverting toilet (Separett) and waterless urinal are utilized. Separated urine is collected in a container and hauled away from the home. Solids are dried using a 12-V direct current fan and can either be burned or disposed of in the local landfill.
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> *Wash water (nonconsumptive use and no household withdrawal)*: Gray water is physically and chemically treated in daily batches through concentration of the associated membrane process feed water (i.e., membrane reject is returned to the associated feed tank). First, screened wastewater from the kitchen sink, laundry, bathroom sink, and shower are treated by soap removal through foam fractionation and particle filtration (series of cartridge filters); membrane reject is returned to the gray water tank. Second, nanofiltration (Filmtech NF270-4040) operated at 15% recovery is used to remove the bulk of organics; reject is returned to the nanofiltration feed tank. Third, by loose reverse osmosis (Filmtec L LE 4040) operated at 15% recovery (reject is returned to the reverse osmosis tank), the treated water is irradiated with at least 186 mJ/cm^2 of ultraviolet light (two Viqua VH200 in series) before being stored in the wash water tank ready for in-home use. A small amount of ozone is used to maintain wash water quality by passing ambient air by an ozone-generating ultraviolet light (Viqua S2Q-OZ).

Table 1 Summary comparison of system designs by system developer

System developer	ANTHC	UAA	DOWL	Summit
Design household size (# of adults)	5	4	4	4
Drinking water system				
Design daily drinking water volume (gal)	No separate drinking water system. All water produced from PASS is designed to meet drinking water requirements	2	2	2
In-home storage volume (gal)		5	50	2–5
System location in home		In counter	On counter	Wall mounted
Locations of drinking water spigots		Kitchen sink, bathroom sink	At location of device	Kitchen sink, bathroom sink
Recommended drinking water source		Community watering point	Homeowner's choice	Homeowner's choice
Drinking water treatment		1-μm cartridge filtration-UV	Impregnated gravity ceramic disk filter	50-μm zeolite cartridge filter, 1-μm cartridge filter, ultrafiltration, disinfection media, carbon block filter
Toilet				
Toilet type	Separett	Separett	Saniflo Sanicompact 48	1: Separett or 2: Raritan Elegance
Urine diversion	Yes	Yes	No	1: yes; 2: no
Solids handling	Municipal solid waste	Municipal solid waste	Wastewater hauled to local lagoon	1: municipal solid waste; 2: wastewater hauled to local lagoon
Requires power	Yes	Yes	Yes	Yes
In-home fixtures				
Bathroom sink	Yes, wastewater combined with urine	Yes, wastewater treated for reuse	Yes, wastewater treated for reuse	Yes, wastewater treated for reuse
Shower	No	Yes, wastewater treated for reuse	Yes, wastewater treated for reuse	Yes, wastewater treated for reuse
Laundry	No	Yes, wastewater treated for reuse	Yes, wastewater treated for reuse	Yes, wastewater treated for reuse
Kitchen sink	Some homes, wastewater disposed to ground	Yes, wastewater treated for reuse	Yes, wastewater hauled to local lagoon	Yes, wastewater hauled to local lagoon
Wash water system				
Treatment	Cartridge filtration, chlorination	Foam fractionation, cartridge filtration, NF, RO, UV, O3	Zeolite, GAC, UF, bromine	Foam fractionation, MBR, UF, UV, chlorine
Water reuse	No	Yes	Yes	Yes
Weekly water availability (gal)	As much as desired (self-haul)	406	406	406
Weekly wastewater production (gal)	All not consumed	35	90	70–120
Weekly water added (gal)	As much as desired (self-haul)	35	90	70–120
System location	In-home	In-home or in attached building	Attached building (vestibule)	In-home

The system provides 420 gal weekly (15 gal per person per day) producing about 35 gal per week of concentrated gray water and thus requiring about 35 gal of water (i.e., rain, ice, pond/stream, washeteria) to replace the withdrawn concentrated gray water. Provided wash water is of high quality but not recommended for drinking. System provides at least 7-log bacteria and virus reduction and water of about 0.1 NTU turbidity, no color, no odor, and less than 1 mg-C/l organic carbon.

(WIHAH presentation 2016 and provided handout).

DOWL Alaska The DOWL team has expertise covering international and arctic water and sanitation technologies for communities with inadequate water and sewer service. The team emphasizes their "co-development" approach, which integrates significant user input in their design (State of Alaska n.d.-b n.d.-c). Their system consists of two systems, a point-of-use drinking water system and a separate wash water system. The drinking water system is a countertop system located in the home in a location of homeowner preference. The wash water system is located in a super-insulated vestibule attached to an exterior wall of the home, so that it does not take up limited space inside a home and does not require a separate heating source. These systems are briefly described as follows:

Drinking water: Two stacked 5-gal buckets provide raw and filtered water storage. A porous ceramic disk filter (supplied by IMERYS) in the top bucket removes turbidity and bacteria from water and transfers filtered water to the sealed bottom bucket for safe storage; a plastic spigot is used to withdraw filtered water from the bottom bucket. If desired, a third bucket with a perforated bottom can be nested inside the top bucket to melt ice into the lower bucket. The team is currently partnering with IMERYS to test a ferric nitrate-coated ceramic disk filter to remove viruses.

Toilet/blackwater system: Low-volume flush toilet. The team has not identified the final unit but is experimenting with three units with flush volumes ranging from 0.33 to 1.25 gal per flush (gpf). Early testing indicates the Saniflo Sanicompact 48 performs better than the other models being tested. Kitchen sink wastewater is directed to the same tank as the toilet wastewater and hauled from the home.

Wash water system (nonconsumptive use; *kitchen sink and toilet flushing water is disposed after use)*: Wash water (or gray water) collected from the bathroom sink, shower, and laundry fixtures is treated and recycled through the household plumbing system to all fixtures. Wastewater collected from the kitchen sink and toilet is stored in a separate blackwater tank, until it is hauled from the home. Wash water treatment is currently achieved on demand using a dual-media filter/adsorber (1 ft^3 of 14 × 40 mesh Micro-Z zeolite supplied by Watts, and 2.25 ft^3 of 8 × 30 mesh bituminous granular activated carbon supplied by Calgon Carbon) loaded in a common pressure vessel and subsequently disinfected by ultraviolet light (dual-lamp Cactus UV system; 90 W to deliver a UV dose of at least 200 mJ/cm^2 at a flow of 2 gpm). However, the team has plans to add a Pentair Freshpoint ultrafiltration (UF) unit downstream of the dual-media filter for improved turbidity and bacteria removal and a bromine bead "slow release" disinfection unit which would replace the UV system for improved virus removal with no electrical power requirements. On average, water is reused approximately four times before it leaves the system through the kitchen sink and toilet. The on-demand treatment system has sufficient capacity (>5 gal per minute) to supply water to one or multiple fixtures at the same time.

The system's ability to produce 420 gal weekly (15 gal per person per day) has been demonstrated through ongoing prototype testing. To produce 420 gal, approximately 90 gal of blackwater needs to be hauled from the home and 90 gal of raw water (i.e., rain, ice, pond/stream, washeteria) needs to be brought to the home to replace the withdrawn wastewater. Note that at the time of writing, DOWL is in the process of modifying the treatment process to add the UF and bromine treatment units as discussed above.

(WIHAH presentation 2016 and email communication 20 and 27 December 2016).

Summit Consulting Services, Inc. The Summit "team is focused on improving the ease of sanitation for the end user by reducing the amount of water hauled and incorporating sources such as a rain water catchment system" (Summit Consulting Services, Inc. n.d.). Their design is meant to be flexible, to fit appropriately within each home's existing structure, and tailored to meet individual families' needs. Their system consists of three systems: a drinking water system, a toilet/blackwater system, and a wash water system. The drinking water system is a wall-mounted membrane system that provides water to two drinking water spigots located at the bathroom and kitchen sinks. The wash water system is located within the home with tanks installed within the wall framing and the membrane treatment system located in the bathroom. These systems are briefly described as follows:

Drinking water: The system is designed to treat water from the local watering point or raw water of the homeowner's choice. The system consists of a series of filters; two prescreening filters (a Premium SureSafe silver zeolite 50-μm filter and an AMI 1-μm filter), a Dizzer P 2521-1.0, UF unit with a 0.02-μm membrane, a Silecte Quantum disinfection media, and a HBC WaterBetter, 10-μm carbon block filter to remove taste and odor.

Toilet/blackwater system: The blackwater system consolidates flow from one of two toilet options (Separett Villa

9200 or Raritan Elegance), the kitchen sink, dishwasher, and utility sink. Blackwater is stored in a tank in the bathroom, and discharge through the wall is provided with a Jabsco macerator pump.

Wash water system (nonconsumptive use; kitchen sink, dishwasher, utility sink, and toilet flushing water is disposed after use): Wastewater (gray water) collected from the bathroom sink, shower, and laundry fixtures is made available for reuse after treatment. Treatment includes a buffer tank equipped with a foam fractionation system to remove soap. This tank provides water to an UltraGTS membrane bioreactor (MBR) from WasteWater Australia where a 0.1-μm membrane is used. Water passing through the MBR is further treated by a 0.02-μm ultrafilter (WMZ-14021A-116 from Applied Membranes) prior to ultraviolet disinfection (supplied by WasteWater Australia and providing 186 mJ/cm^2 at 1.8 lpm).

The system provides 420 gal weekly (15 gal per person per day), producing about 70–120 gal of wastewater and requiring 70–120 gal of water (i.e., rain, ice, pond/stream, washeteria) to replace the withdrawn wastewater. Water usage is highly dependent upon the homeowner's preference for the toilet (i.e., dry separating or flush toilet) and how the toilet is used.

(WIHAH presentation 2016, provided handout, and email correspondence 6 December 2016).

Portable alternative sanitation system

In 2013, the Alaska Native Tribal Health Consortium (ANTHC) started an initiative of its own motivated by the desire to ensure basic water and sanitation needs for all rural Alaska communities—beyond the hand basin and honey bucket. ANTHC partnered with Cold Climate Housing Research Center and others to design a system that would be as follows:

- an immediate improvement to quality of life and public health for unserved communities;
- acceptable to the communities;
- affordable for all households to operate and maintain;
- portable in case of necessary relocation within or to a new community;
- complementary to traditional practices (e.g., using rain, river water, or ice as a water source); and
- sufficient to meet basic health needs by providing clean drinking water, a sink with flowing water, and reduced exposure to sewage.

The resulting solution was the Portable Alternative Sanitation System, or PASS, a system designed to complement existing water infrastructure in communities, such as the public watering point and traditional untreated sources such as springs, streams, ice, and snow.

The key components of PASS are the following:

Rain catchment system: For an 800-sq-ft home located in Kivalina with a roof catchment area of approximately 1200 sq ft, it is possible to recover nearly 3000 gal or more of rain each year to supplement the quantity of water hauled to the home.

Water storage tank: The 100-gal tank feeds water to fixtures via gravity and does not require electricity.

Low-flow sink and waterless urinal: The low-flow faucets in the bathroom and kitchen (0.25 gal per minute) and waterless urinal conserve water while providing for hygiene and sanitation needs.

Gray water tank: The gray water tank purges urine from the toilet and water from the bathroom sink into a buried seepage pit located adjacent to the home when full. It should be noted that use of buried seepage pits is appropriate for Kivalina because of the local soils.

Separating toilet: A dry urine-diverting toilet (Separett) separates out the liquid into the gray water tank and dries the fecal solids, thereby reducing exposure to waste and reducing the frequency of hauls and the consequential intensity of the labor. The solids are then hauled to the local landfill.

Integrated ventilation: An energy-efficient combined ventilation system dries the human waste, reduces odors, and ventilates the home.

Water treatment system: The water treatment system incorporates two dual-gradient filters (the first filter is a Pentek dual gradient 4-1/2-in. diameter by 10-in.-long Model DGC2501 (25/1 μm) cartridge and the second one is a Pentek FloPlus 4-1/2 diameter by 10-in.-long Model FloPlus 10BB, 0.5-μm cyst-rated activated carbon filter cartridge that reduces taste and odor, removes some organics, and provides protection from cryptosporidium and giardia) and chlorination for point-of-use treatment to ensure the water is safe to drink regardless of its condition upon entering the system.

The PASS units were piloted in nine homes in Kivalina, Alaska from August 2015 to September 2016. The units cost US$47,726 for materials, labor, and installation-related expenses. This cost is specific to the community of Kivalina due to the high cost of freight, the small size of the project, and the location of the homes in an area rich with historic artifacts. The cost of archeology alone to monitor the excavation of each seepage pit averaged US$2600 per home. The monthly operations and maintenance costs including energy and replacement parts are estimated to be about US$30 per month, which is primarily driven by the addition of the ventilation fan in the bathroom and heat trace on the drainpipe. This cost however does not include the cost of water from the washeteria or the heat that is required to compensate for ventilation of the home. These costs can vary widely depending on homeowner preference for water source (treated or nontreated) or ventilation.

The pilot data collected resulted in modifications to the installations to further improve operation and ensure long-term sustainability of the systems. Health impact was not measured during the pilot due to the small sample size. However, without being asked about health, three families, all with children in the home, shared with the ANTHC team during follow-up visits that they felt that their families were healthier following installation and use of the PASS unit in their home (ANTHC internal data).

The next phase of the initiative will be to install the refined units in up to 20 more homes. The systems will be offered as modular options so that households may choose the configurations and accessories that individually will work best for them, for their lifestyle, family needs, and financial situations. It should be noted that the PASS design and operational philosophy is focused on how sanitation is addressed within the home, with an aim to immediately improve conditions, and not on a specific water quantity target. The design of the system assumes a fully functional washeteria for bathing and washing clothes, thus offsetting the quantity of water needed within the home for sanitation purposes. The benefits of frequent and effective handwashing, safe handling of human waste, and pathogen-free water are realized by the PASS approach with an understanding that the quantity of water will be far less than what will be offered by a fully piped system or a recycling-type system such as those being considered as part of the Alaska Challenge project.

End-user feedback provided at water innovations for healthy Arctic homes meeting

The Alaska Water and Sewer Challenge systems and the PASS units were described at the Water Innovations for Healthy Arctic Homes meeting in September 2016. Twenty-six potential end users were flown in from 18 different rural Alaska communities to participate in the meeting and provide feedback on the systems. Zender Environmental facilitated the feedback session and provided conclusions in their final report (Zender Environmental Health and Research Group 2016). The participants shared that their feedback was preliminary and that the real test would be functionality on the ground in communities. The PASS units have been initially piloted in Kivalina, and the Alaska Water and Sewer Challenge will test their systems in communities in the next phase of the Challenge.

Each system received specific feedback from end users with some overarching priorities arising. First, participants were concerned about the cost of the systems to install and then operate and maintain over the long term. Many residents have limited disposable income, especially elders, and for those that are able to pay a higher cost, participants communicated that they do not want to pay a premium price for less than piped service. Second, simplicity is valued. Participants voiced concern over the complexity of the operations and maintenance necessary to run some of the systems. Community residents do not want to have to rely on outside labor or replacement parts that are hard to find. Other concerns included apprehension about water reuse in the Challenge systems, its safety, and the systems' functionality with traditional practices such as processing wild game as well as questions over freezing and how systems would hold in extreme conditions.

Dump the Bucket

"Dump the Bucket" is an initiative of the Office of Environmental Health and Engineering at the Yukon Kuskokwim Health Corporation (YKHC). During phone and email communication in December 2016, Brian Lefferts and Jennifer Dobson of YKHC explained the initiative that began with seed money from a crowdfunding campaign. YKHC is testing a variety of gray water treatment technologies that utilize existing water delivery systems and recycles and reuses water in the home. The goal of the team is to find a system that is reliable, consistent, robust, energy efficient, and an affordable method for delivering treated gray water in a home.

YKHC is testing off-the-shelf treatment systems with basic modifications to better fit the conditions of the homes they work in. Once a system is identified that meets their parameters, the team plans to work with the manufacturer of the system to then tailor it prior to widespread dissemination. Four systems were tested in 2016. None of the systems met all of the targets for each parameter YKHC had set. A second round of testing will begin in January 2017. Once the team identifies a system that meets their parameters, they will test it in a mock home setting.

(Personal communication, Brian Lefferts and Jennifer Dobson, 5 December 2016 and email communication 13 December 2016).

Likely future developments

These initiatives are critical steps towards providing basic water and sanitation to households across rural Alaska. The experiences thus far have highlighted likely future developments that will emerge in the field. One important lesson is that community members have different needs and wants at the household level. Modular systems tailored for individual communities and households and with options are going to be important to meet different needs and financial situations. In tandem, an understanding and acceptance of what water uses are necessary in the home (e.g., handwashing) or could be provided centrally (e.g., laundry) will likely continue to influence system designs.

Another likely future advance will be the development of local infrastructure necessary to support the decentralized systems. That development will involve social engineering to improve on existing support structures and increase their functionality and sustainability. For example, limited decentralized support systems exist at the local level in communities with small vehicle haul systems, and rural Alaska communities have access to regional tribal utility support to help troubleshoot problems and make repairs, though the resources are limited. In order to sustain systems like those described in this paper, communities or regions will most likely have to develop a support network that provides access to assistance and parts to maintain and repair systems as necessary. Most important to the success of the systems and the support network though will be a focus on the homeowners and their operations and maintenance practices—a great design is doomed to fail if used incorrectly.

We will likely see more and more of these initiatives to address basic water and sanitation needs in rural Alaska—some focused primarily on drinking water, others on providing greater quantities or water at the household level, and another group focusing on the waste stream. The need is growing, yet funding resources continue to decrease. Rural Alaskans desire an improved quality of life over the hand basin and the honey bucket, and we will see more focus on projects to provide a higher level of service while also thinking "outside the pipe."

Recommendations

The review of the current initiatives and their lessons learned highlighted some gaps that need to be addressed. The Alaska-specific research needs are (1) how water is used in the home at each water service level; and (2) evaluate the 50 l/c/d recommendation for quantity of water required for a low level of health concern for application in an Arctic context and how it might vary with technologies such as low-flow devices. More research on these topics will better inform standards for organizations to target through their research and development of new systems.

Additionally, we recommend that end users be more integrated into the design and implementation process of new systems. A system can be designed to perfectly treat and provide water, but the implementation of that system in a home will not be successful if it is not first accepted and then properly operated and maintained by the household members. End-user engagement and participation throughout the entire process as well as adequate homeowner training is critical.

Finally, new initiatives and systems need to have monitoring, evaluation, and information dissemination built into the project. Continuous evaluation will provide the opportunity to make improvements as problems are identified, incrementally resulting in a better end product. The data and lessons learned should also be shared, as the initiatives highlighted in this paper have attempted to do. The field needs to collaborate in order to better serve the thousands of homes in rural Alaska that have to rely on hauling water to the home, living off less than 2 gal per person per day and dealing with a 5-gal bucket for their toilet needs.

Compliance with ethical standards

Conflict of interest Korie Hickel, John Warren, Mia Heavener, Timothy Thomas, and Jack Hebert are all members of the team that designed and piloted the PASS units. Aaron Dotson is a member of the UAA Water and Sewer Challenge team, and Jack Hebert's organization, Cold Climate Housing Research Center, has a representative on the DOWL and UAA teams.

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