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CLIMATE CHANGE AND HUMAN HEALTH: INFRASTRUCTURE IMPACTS TO SMALL REMOTE COMMUNITIES IN THE NORTH

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ABSTRACT

In northern regions, climate change can include changes in precipitation magnitude and frequency, reductions in sea ice extent and thickness, and climate warming and cooling. These changes can increase the frequency and severity of storms, flooding, or erosion; other changes may include drought or degradation of permafrost. Climate change can result in damage to sanitation infrastructure resulting in the spread of disease or threatening a community's ability to maintain its economy, geographic location and cultural tradition, leading to mental stress. Through monitoring of some basic indicators communities can begin to develop a response to climate change. With this information, planners, engineers, health care professionals and governments can begin to develop approaches to address the challenges related to climate change.
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INTRODUCTION

Communities in the circumpolar north will be impacted by climate change in the years to come, and this geographic area is presently experiencing more pronounced changes than the rest of the world. Retreating sea ice has already had devastating impacts to some arctic coastal communities in the form of accelerated erosion of shore lines. Extreme weather events and thawing permafrost will continue to impact Arctic infrastructure in the future.

The issue of climate change has been addressed in a number of recent studies (1). Many of these studies focused on global issues and did not specifically address impacts within the Arctic. One recent study, the Arctic Climate Impact Assessment (ACIA) focused on climate change impacts within the circumpolar north (2). The study concluded that "the Arctic is now experiencing some of the most rapid and severe climate change on Earth. Over the next 100 years, climate change is expected to accelerate, contributing to major physical, ecological, social, and economic changes, many of which have already begun." Some of the key findings of this study concluded:

- Arctic climate is now warming rapidly and much larger changes are projected.
- Arctic warming and its consequences have worldwide implications.
- Many coastal communities and facilities face increasing exposure to storms.
- Thawing ground will disrupt transportation, buildings, and other infrastructure.

This paper will focus specifically on small remote Arctic communities and the potential for climate change to indirectly influence human health. The objective of this paper is to provide an overview of the potential health issues associated with climate change impacts to infrastructure in the north.

METHODS

The lead author and contributing authors participated specifically in the development of the Human Health chapter in the ACIA. The lead author's experience in planning, design, and construction of sanitation facilities and housing in the arctic and the two contributing authors' experience in public health in the Arctic are the basis for this paper.

Climate change

The circumpolar region of the world shares common characteristics such as sparse population, harsh climate, and seasonal extremes of daylight hours and temperatures. In the circumpolar north, communities are remotely located and economic opportunities are often limited. The environment is generally harsh and structures or entire communities are often built on permanently frozen ice-rich soils.

In the past, many people of the north were not confined to live in a single location. Instead they moved as necessary when they could no longer support their needs in a specific location. In many cases, this transition away from the nomadic lifestyle has been a relatively recent event. The construction of schools, airports, docks, stores, and other infrastructure has resulted in the formation of permanent establishments. These establishments force residents to subsist on locally available resources and accommodate the local environment, an environment which has in the past changed slowly but in the future may undergo rapid and substantial changes.

Temperature measurements (Figure 1) and sea ice observations (Figures 2a and 2b) indicate a warming trend. Whether these changes are affected by man or simply part of a natural cycle, we must begin preparing now in order to minimize potential impacts to human health in the future.

Impacts to sanitation facilities and health

Sanitation is necessary to prevent the spread of disease. As population densities increase, the need for sanitation becomes critical to public health. The devastation of communities by flooding, severe storms or other sudden disasters can be followed by the spread of disease. The magnitude of the health crisis is dependent upon resources that are available to respond to the emergency and the time frame in which resources are made available.

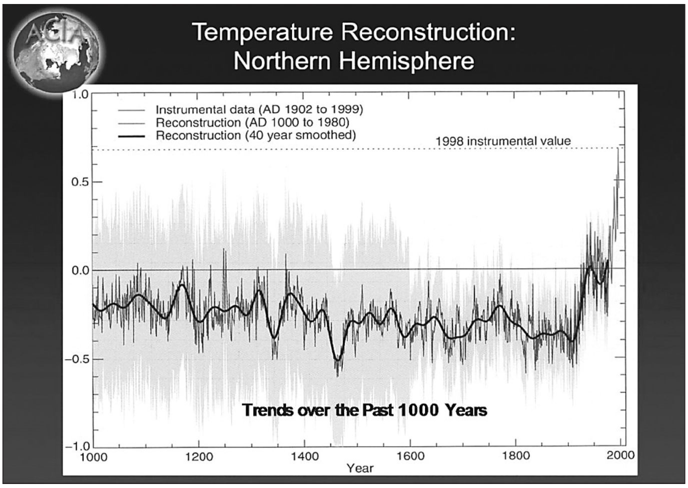

Figure 1. Temperature reconstruction, Arctic Climate Impact Assessment (Dr. Robert Corell's Testimony before The Committee on Commerce, Science and Transportation, United States Senate, March 3, 2004).

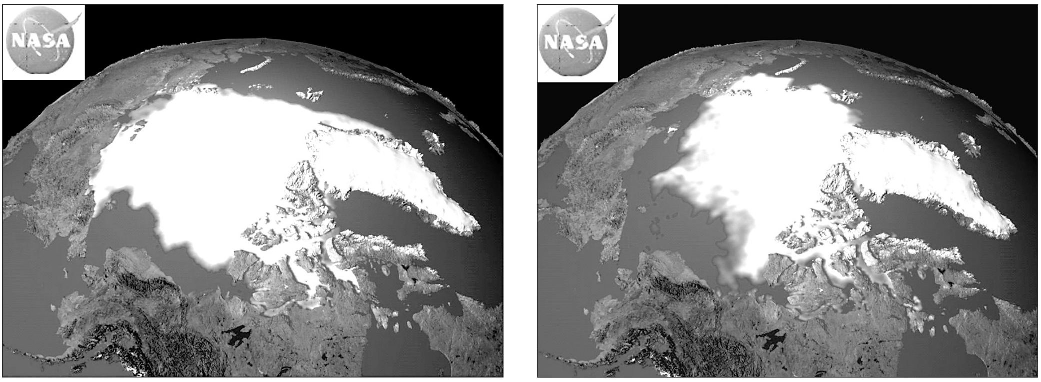

Figure 2. Summer Arctic Ice Extent in a) 1979 and b) 2003 (ACIA, Impacts of a Warming Arctic, Arctic Climate Impact Assessment, 2004).

Sanitation systems that provide high quality water and adequate quantities of water offer protection against chemical constituents, waterborne diseases, and diseases related to inadequate personal hygiene. The World Health Organization's (WHO) 2002 World Health Report (3) listed unsafe drinking water combined with inadequate sanitation and hygiene as sixth in the top ten health risk factors leading to disease, disability, and death worldwide. In Alaska, remote rural communities with inadequate sanitation systems accounted for more than 72 percent of 596 reported cases of hepatitis A in 1988 (4).

In the Arctic, sanitation facilities can include varying levels of service. In the most basic form, water and wastes are hauled to and from the residence by hand. This method represents the lowest level of service. Providing a community water and wastewater haul system can raise the level of service. Such systems provide greater amounts of water for sanitation purposes and, therefore, improve the level of community health. Piped utility systems provide the highest level of service. These systems provide ample amounts of water and commensurate health benefits. Understanding the impacts of climate change on these sanitation systems can encourage the implementation of monitoring activities and the development of prevention measures.

Water systems

Water systems include a water source, storage facility, and distribution system. Water sources contaminated with biological, chemical, or mineral constituents require treatment to render the water supply safe for human consumption. In the United States, it is estimated that contaminated drinking water causes more than 900,000 people to fall ill and up to 900 to die annually (5). In 1993, inadequate water treatment in one city caused an outbreak of approximately 403,000 illnesses, 440 hospitalizations, and 50 deaths (6).

Water supplies are necessary primarily for personal hygiene, cleaning, drinking, and cooking. Due to the labor involved, when water is hauled individually it is used for drinking and cooking and is used sparingly for hygiene and cleaning (7). In more sophisticated systems, water is used to transmit human waste from residences through haul tanks or pipelines to the point of treatment and/or disposal.

Water source

Arctic surface water sources include streams, rivers, lakes, tundra ponds, or manmade impoundments that capture snow and rain. A surface water source is generally at greater risk of contamination by pathogens than groundwater supplies. Therefore, surface waters require some form of treatment to ensure that the water is safe for consumption. Naturally occurring organic or inorganic substances can exist in both surface water and groundwater supplies. These contaminants must often be removed early in the treatment process to improve aesthetics or to make the water safe for consumption. Some of these organic or inorganic contaminants may also form carcinogenic byproducts in the presence of chlorine or other disinfectants. Climate change impact mechanisms for water sources include the following:

- Limited recharge (restoration) for groundwater supplies due to less frequent precipitation (drought) or intense but less frequent rainstorms (water lost to runoff).
- Reduction in available water in surface water impoundments, such as lakes, tundra ponds or reservoirs, due to drought, melting permafrost or intense storms (causing watersheds to release water too rapidly).
- Contamination of a coastal groundwater source by sea water due to sea level rise.
- Contamination of coastal surface water sources by sea water due to storm surge flooding or sea level rise.
- Contamination of coastal community river intakes due to the saline wedge (stratification of fresh water over seawater) penetrating farther distances upstream as the result of rising sea levels or storm surges.
- Damage to water impoundment structures due to intense storms exceeding the design capacity of the overflow structure.
- Damage to intake structures due to melting ice-rich permafrost and subsequent loss of foundation support.
- Damage to facilities adjacent to streams due to intense rain storms and subsequent erosion.

- Surface water contamination by wildlife species extending their range further north such as Beaver (*Castor canadensis*) changing the course of streams and introducing the zoonotic protozoan parasite *Giardia lamblia*, to surface water supplies.

Water treatment

Water treatment systems are designed to remove contaminants and inactivate pathogens. The design of the system is based on the varying properties of the water source. Climate change can degrade the quality of a water source or introduce contaminants that render the treatment process ineffective. Climate change impact mechanisms for water treatment systems include the following:

- Rising seawater levels can contaminate a groundwater or surface water source through one of the previously mentioned mechanisms. The process required to treat a water source contaminated with sea water is specialized, complex, and costly.
- Intense rainstorms can increase turbidity, pathogen contents, and organic concentrations in a water source. A substantial increase in these contaminants can exceed the ability of a water treatment system to produce safe and palatable water.
- More frequent and severe algae bloom in lakes or ponds can occur due to warming weather and longer dry periods. Algae may clog water treatment filters and increase the formation of dangerous disinfection byproducts (8).

Water distribution

Water distribution in northern communities may consist of self-haul, community-haul, or piped utility systems. Self-haul systems require minimal infrastructure because water can be hauled by foot, sled, or small all-terrain vehicle (ATV). Community-haul systems use larger haul containers, which require larger vehicles and/or trailers and therefore substantial all-weather accesses. These distribution systems require access roads and boardwalks to be maintained in passable condition in order to remain viable.

In the Arctic, piped utilities rest on aboveground supports or are buried belowground. The more desirable and conventional belowground installations require thaw-stable soils. When thaw-stable soils do not exist, piped utilities are usually constructed aboveground to minimize the potential for melting the permafrost and damage due to subsequent loss of foundation support.

When a piped distribution system is used, piping must remain sound to ensure the water supply remains safe for human consumption. A breech in a pipeline can allow contamination of the water to occur within the distribution system. In 1989 contamination of the water supply caused by a pipeline breech in Cabool, Missouri, resulted in 243 illnesses and 4 deaths (9).

In the Arctic, piped distribution systems continuously circulate water for freeze protection. Loss of water in a distribution system during cold weather can result in loss of circulation and complete freeze failure of the system (7). Some climate change impact mechanisms for water distribution systems include the following:

- Flooding caused by storm surges or heavy rainstorms can damage roads, boardwalks, water storage facilities, and aboveground pipelines. In the north, floodwaters can include ice, which can substantially increase this damage.
- Roads, boardwalks, pipelines, and water storage facilities can be adversely impacted by erosion. Riverbank erosion may accelerate during late season flooding (when river banks are not frozen). Coastal communities may experience accelerated erosion along shorelines due to thawing permafrost, severe storms, rising sea levels, or reduced periods of sea ice cover (loss of protection from winter storms).
- Melting permafrost can result in the loss of foundation support for aboveground or belowground pipelines, water storage facilities, access roads, or boardwalks. Loss of foundation support for a pipeline can damage the facility and allow contamination of the water supply to occur (10). Damage to storage facilities, access roads, or boardwalks can render a water distribution system inoperable.

Wastewater systems

Wastewater systems collect human waste and provide treatment and ultimate disposal. Improper methods of collecting, treating, or disposing human waste have been attributed to numerous outbreaks of infectious disease (4). In Sweden, 3,600 people became ill at a ski resort through a cross connection between a drinking water reservoir and a sewage pipeline (11). In Alaska, between 1972 and 1995 more than 7,000 cases of hepatitis A were reported to the State of Alaska Department of Health & Social Services (12). The method of disease transmission was via the fecal-oral route, and inadequate sewage disposal was cited as a major factor (13).

The level of service provided by wastewater collection, treatment, and disposal systems varies in the north. In some remote Alaskan villages, residents use small buckets to collect human waste. The buckets are then carried by hand to centrally located disposal points where wastes are dumped into receptacles or are carried directly by the resident to the sewage disposal facility. Hauling wastewater by hand is the most unsanitary form of collection and, therefore, represents the lowest level of service.

Holding tanks provide an improved level of service. This method is used when a piped collection system is not feasible. The tanks are located adjacent to structures and are pumped (contents removed) by a community or commercial based service. Holding tanks provide an improved level of service, but water usage is minimal because of the limited capacity of the tanks and the high labor cost for the service.

Piped utilities provide the highest level of service. Flush toilets are normally used in piped systems, and water supplies and wastewater removal systems can provide ample water for personal hygiene, cleaning, laundry, or other sanitation needs.

Wastewater collection

Wastewater collection systems are designed to minimize the potential for human contact with sewage. Disease transmission can occur in populations where collection systems are inadequate and contact with wastewater is not controlled (14, 15). Failed collection systems can discharge human waste to the environment, contaminate water supplies, and transmit disease via human contact.

Many of the affects of climate change on water distribution systems also apply to wastewater collection infrastructure. Access ways must remain in passable condition throughout the year for haul systems to operate, and pipeline integrity must be maintained for piped wastewater collection systems to function properly.

Wastewater treatment and disposal
Wastewater treatment for small remote Arctic communities is generally limited to simple systems. Mechanical treatment methods, such as aeration (secondary treatment), are not typically used due to the cost and complexity of operation (7).

In the north, individual wastewater treatment facilities include pit privies (outhouses) and septic systems. Community facilities typically include earthen lagoons, tundra ponds, septic tanks with ocean outfalls, and septic tanks with drainfields (when favorable soils exist). Climate change impact mechanisms for wastewater treatment and disposal systems include the following:

- Damage to wastewater lagoons, tundra ponds, or septic systems by flooding or storm surges (Figure 3).
- Damage to wastewater facilities by riverbank or shoreline erosion.
- Degradation of ice-rich permafrost beneath wastewater treatment facilities causing the loss of structural support.

Solid waste systems
Solid waste collection and disposal in the Arctic is performed with relatively conven-

Figure 3. Fall 1999 Honey Bucket Lagoon waste spread by storm surge flooding, Kipnuk, Alaska. Photo by Mike Marcaurele.

tional methods. Recycling, incineration, and baling facilities are rare and generally limited to larger communities. Collection in very small communities is typically by self-haul. Larger communities often use community-haul systems.

Solid waste disposal sites in the Arctic are generally frozen. Landfill wastes are often mixed with snow during winter operations and later covered with soil during the summer months. After adequate soil cover is provided, wastes may then remain permanently frozen. Climate change can impact solid waste facilities as follows:

- Access routes can become impassable for collection and disposal to occur.
- Flooding or erosion intercepting a solid waste landfill can spread waste and contaminate water supplies.
- Frozen solid waste materials can thaw and release contaminants into the environment through runoff.

Impacts to community and mental health

Entire communities can be impacted by climate change through the mechanisms that have been previously discussed. Flooding, erosion, or melting permafrost can destroy structures and make a specific location uninhabitable (Figure 4). Up to 184 communities in Alaska are being impacted by erosion (16). Several of these communities are presently faced with the prospect of having to relocate, and the costs for relocating are expected to be high (16).

Drastic changes to a community's physical environment will affect the everyday life and health of the population. Changes in access to hunting or fishing may limit both occupational opportunities and leisure activities and will affect economy and food availability as well as social relations linked to hunting and fishing practices, food sharing etc. Permafrost thawing, erosion, or flooding can force relocation of a community and families moving will have to adapt to new ways of living, may face unemployment and will have to integrate and create new social bonds. Relocation may also lead to rapid and long-term cultural change and loss of traditional culture, which can create distress and mental health challenges.

The ACIA describes the term acculturation as the cultural and psychological changes that result from continuous contact between people belonging to different cultural or ethnic

Figure 4. Fall 2003 Coastal erosion damage, Shishmaref, Alaska. Photo by Curtis Nayokpuk.

groups. Climate change can indirectly initiate the acculturation process by forcing people to behave in new ways, change their ways of living, and replace or drop old traditions (17). If the acculturation experience overwhelms an individual with a feeling of loss of control, the individual may experience depression and anxiety, substance abuse, or suicide (17).

The rapid social, cultural, and economic transition that Arctic communities have seen over the past 50 years has influenced lifestyles, as well as individual and community health. These changes are likely to be affected and even accentuated by climate change in the future. Climate change has the potential to influence the rapid changes ongoing in communities today by challenging individuals' and the community's relationship with their local environment, which has for thousands of years been the basis of their identity, culture, and well-being.

Recommendations for response to climate change and health

A good understanding of the link between climate change and human health is important to prepare for the future challenges projected for the Arctic. Health impacts related to climate change are likely to vary across communities and regions with both positive and negative influences on human health. In response to these impacts, communities need to develop strategies to take advantage of opportunities and to minimize risks.

Communities

The identification, selection, and monitoring of some basic indicators for climate and health is one tool communities can use to help develop their response to these changes. This information can support the community's capacity to know what changes are occurring, what changes are likely to take place in the future, and what impacts these changes may have. The following are some basic indicators for water and sanitation systems that a community can begin monitoring to prepare for the affects of climate change:

- Trends in the saline content of coastal fresh water sources
- Concentrations or types of contaminants in the community's water source
- Trends in operational costs for the water or wastewater system
- Repair costs for sanitation infrastructure, boardwalks, and roads
- Movement of structures located on permafrost
- Shoreline or river bank erosion rates
- Flood depth and return frequency
- Regulatory noncompliance events for sanitation systems
- Pollution of waterways caused by human waste or solid waste
- Loss of water containment in tundra ponds, lakes, reservoirs or lagoons
- Incidence of waterborne diseases
- Trends in river or sea ice thickness, duration, or extent
- Trends in wind magnitude or frequency
- Trends in snow depths
- Trends in rainfall
- Trends in surface air temperatures

Engineering

Engineers and community planners must recognize the potential impacts of climate change and begin to develop approaches to address these challenges. The design of infrastructure is often governed by design criteria based on historic data. For example, the capacity of a drainage structure is determined by historic precipitation measurements or the design of a building structure considers historic environmental conditions such as air temperatures, snow loads, wind loads and foundation conditions. A substantial increase in precipitation could damage a drainage structure or an increase in wind or snow loading could cause a building structure to fail. Some considerations to mitigate climate change impacts may include:

1. Monitoring environmental data such as snow depth, wind velocity, precipitation, flood depth, erosion rates or permafrost temperatures
2. Updating environmental data and being more conservative in the application of these parameters
3. Developing community master plans that consider climate-induced changes in the planning for new infrastructure or protection of existing infrastructure
4. Incorporating updated environmental parameters into designs and applying conservative safety factors in the application to engineering designs

Health care

The health care system must be prepared to accommodate increased demands on resources resulting from the spread of disease or stress-related health issues. Some climate change considerations for health care systems include:

1. The potential health impacts of a natural disaster that may be amplified by the harsh environment and limited access
2. The potential health consequences caused by a forced relocation of a community

Government

Governments must recognize that small remote communities in the Arctic will need financial support to adequately address the impacts of climate change. Considerations include:

1. The increased costs of infrastructure repairs that will further burden the limited local economies
2. The impacts to human health resulting from climate change that may be accentuated without adequate resources

REFERENCES

1. IPCC. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2001: 881 pp.
2. ACIA. ACIA Scientific Report: Arctic Climate Impact Assessment. Cambridge University Press, New York, 2005:1042 pp.
3. WHO. The World Health Report 2002: Reducing Risks, Promoting Healthy Life. Geneva, Switzerland: World Health Organization.2002:248 pp.
4. U.S. Congress, Office of Technology Assessment.. An Alaska Challenge: Native Village Sanitation. OTA-ENV-591 (Washington, DC: U.S. Government Printing Office, May) 1994.
5. American Public Health Association (2000). Drinking Water Quality and Public Health. Am J Public Health 2001;91(3):499-500.
6. Craun GF, Nwachuku N, Calderon RL, Craun MF. Outbreaks in Drinking Water Systems, 1991-1998. J Environ Health 2002;65(1):16-23.
7. Smith DW (Tech. ed.), Ryan WL, Christensen V, Crum J, Heinke GW. Cold Regions Utilities Monograph. American Society of Civil Engineers, New York, 1996:840 pp.
8. Singer PC (ed.). Formation and Control of Disinfection By-Products in Drinking Water. Denver, Colorado: American Water Works Association, 1999:424 pp.

9. Fox KR. Engineering Aspects of Waterborne Disease: Outbreak Investigations. Proceedings: 1993 Annual Conference, Water Research, June 6-10, 1993, San Antonio, Texas, American Water Works Association, 1993:85-93 pp.
10. Geldreich EE. Waterborne Pathogen Invasions: A Case Study for Water Quality Protection in Distribution. AWWA Water Quality Technology Conference Proceedings, 1992.
11. Fewtrell L, Bartram J (Eds) Water Quality: Guidelines, Standards and Health: Assessment of Risk and Risk Management for Water-Related Infectious Disease. World Health Organization, IWA Publishing, London, UK, 2000:424 pp.
12. State of Alaska, Department of Health & Social Services. Hepatitis A Vaccine Promises to End Statewide Outbreaks. 1996;Bulletin No. 28
13. State of Alaska, Department of Health & Social Services. Epidemiology of Hepatitis A in Alaska. 1984;Bulletin No. 18.
14. Schliessmann DJ, Atchley FO, Wilcomb MJ, Welch SF. Relation of Environmental Factors to the Occurrence of Enteric Diseases in Areas of Eastern Kentucky. U.S. Public Health Service Publication No. 591, (Washington, DC: U.S. Government Printing Office, April 1958).
15. Indian Health Service.. Criteria for the Sanitation Facilities Construction Program. Washington D.C.: U.S Indian Health Service, Division of Environmental Engineering, Environmental Engineering Branch. 1999.
16. U.S. General Accounting Office. Alaska Native Villages: Most Are Affected by Flooding and Erosion, but Few Qualify for Federal Assistance. GAO-04-142 (Washington, DC: U.S. Government Printing Office, December 2003).
17. Kvernmo S, Heyerdahl S. Acculturation strategies and ethnic identity as predictors of behavior problems in arctic minority adolescents. J Am Acad Child Adolesc Psychiatry 2003;42(1):57-65.

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