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Availability of fresh water in cold climate regions

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Availability of fresh water in cold climate regions

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Abstract: Challenges related to the availability of fresh water in cold climate regions are discussed with emphasis on possible degradation of the quality of drinking water. The permafrost in this region has been consistent in making sure there is little drainage in the ground. This is important, as fresh water is mainly supplied through melting water from snow and ice in the many winter months. Climate change and warmer weather plays a role in heating up the permafrost and increasing the rate of the melting snow. This has an impact on both the amount of water and potentially the drinking quality. In certain cold region areas, fresh water sources are located not far from the shore. With increased shorline erosion due to warming climate, the fresh water supply is in danger of being contaminated by salt water during large storm events. Furthermore, human activities such as road transport and sewage contamination do also have a significant impact on the water's quality. A bowtie diagram will be used to illustrate the different risk factors and suggestions on how to maintain the quality of fresh water supplies in cold climate areas. The primary focus areas will be Isdammen, near Longyearbyen on Svalbard and Utqiaġvik (formerly Barrow), Alaska.

1. Introduction

The access to clean fresh water is one of the most important requirements for a society. Although there are ways to handle situations where the water quality is poor, the preference is to use clean water from the natural environment. The upgrading of the water quality is typically handled by filtering the water or by adding chemicals to ensure bacteria are destroyed. Some societies (for example in the Middle East) are, however, lacking access to clean fresh water so desalination of seawater is necessary [1, 2]. The process is, however, very costly and requires much energy. Smaller and vulnerable societies cannot afford such expensive solutions. This applies to most smaller societies located in cold climate regions. [3, 4]. In these areas the access to clean fresh water is under pressure. The water quality, however, are normally carefully checked and the water is filtered, and it should not be necessary for the population to boil the water to ensure the quality.

According to the Government of Norway, the temperature within the Arctic has been increasing twice as fast as the global average [5]. The pressure on the clean freshwater resources of drinking quality in cold climate regions comes partly from heating of the permafrost in the ground whereby the water locked in shallow dams could disappear [6]. The water quality could also gradually worsen because of increased human activity. In the worst situation, erosion of the shoreline and increased storm surges and wave-heights due to melting of the sea ice (the fetch length for generation of large waves does increase) [7], could cause saltwater to penetrate freshwater reservoirs. Desalination may not be an economic

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option, another freshwater reservoir must be identified and established as the drinking water reservoir for the society.

In this paper we will illustrate the challenges by discussing the clean freshwater availability situation in Utqiaġvik (formerly Barrow), Alaska and Longyearbyen, Svalbard, Norway. Emphasis will be on Longyearbyen, located at 78.25o N as this is the location best known by the authors.

2. Permafrost as a barrier to ensure the integrity of a fresh water reservoir

The ground in the Arctic is usually frozen throughout the year. This permafrost holds a significant quantity of frozen water. We call it permafrost when the ground's temperature stays below zero degrees Celsius continuously for minimum two years in a row [8, 9]. The permafrost may go deep below the surface. During summer, when the snow has melted, the top layer of the soil may begin to thaw, but it can still be frozen solid lower down [4]. As the permafrost ensures that when the ice and snow melts, it does not drain the water away, so water can stay there for a longer period. Even though the top layer may melt, the deep permafrost works as a protective ice shield, preventing water drainage [8, 10]. There are multiple factors that may contribute to melting the permafrost. The main factors are ground and surface warming from climate change. These contribute to the melting and increase of the temperature of the permafrost. Another factor is changes in snow cover, which can also be responsible for the development of this phenomenon [11, 12]. The conditions of the hydrologic environment are changing as the results of the thaw in the permafrost [6]. Figure 1 shows how a warmer climate can affect lakes in permafrost regions. If we compare the left lakes on sketches shown in Figure 1a) and b), we see that the water is starting to drain away more on b) because the permafrost is not keeping it in place. This will reduce the amount of water available in the lake (the reservoir). In the pictures on the right, we see the opposite. On Figure 1b) the permafrost has melted some, but there is still ice left keeping it from draining too much. Some of the melting water goes into the lake and increases the amount of water present. We see here that we can use the state of the lakes as an indicator of how much impact the increased temperature has in certain places.

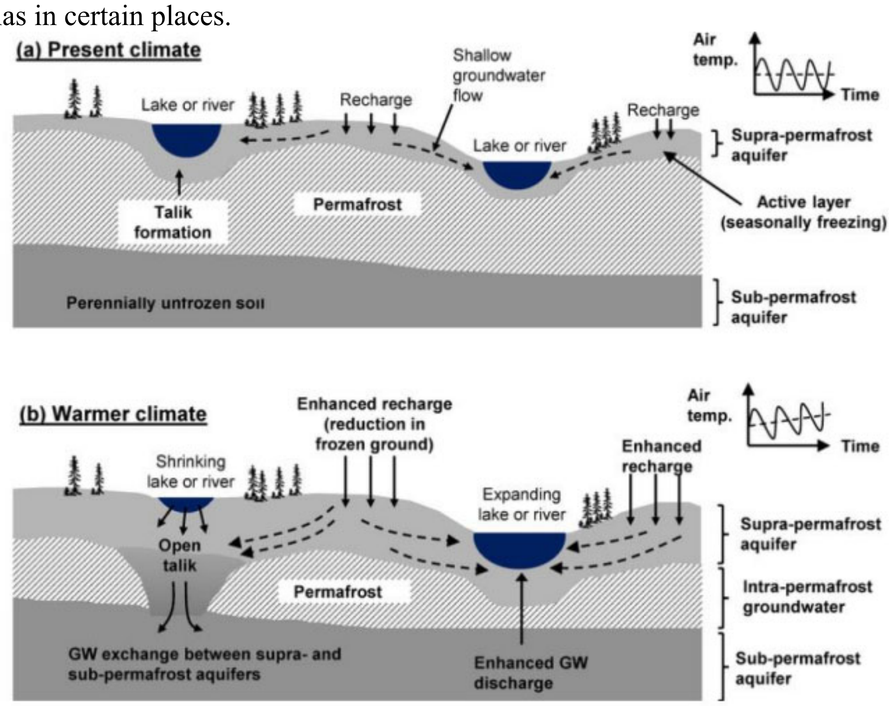

Figure 1. Evolution of the water level in a lake when the permafrost is melting [6].

3. Degradation of water quality due to human activities

Degradation of the quality of fresh water due to human activities is of considerable concern in cold climate as contaminated run-off from human activities will reach the reservoirs more easily than in tempered regions and nothing will disappear into the ground and be filtered, [3, 4]. All contamination is accumulated over the winter season; melting snow where the winter's pollution has accumulated will run-off onto the nearest lake. It should also be noted that foam is used more extensively to extinguish fires in cold climate than elsewhere (as water will freeze to ice when used during the winter), and toxic pollution from the fire-fighting foam may reach the freshwater reservoirs [15].

4. Seawater penetration into a freshwater reservoir

A concern is freshwater reservoirs located close to the shoreline. With decreasing ice cover in the autumn months, the open fetch length will increase causing larger storm surges and generating waves. This cause accelerated shoreline erosion and flooding [6]. Freshwater reservoirs located closer to the waterfront, therefore run an increased risk of being contaminated with salt-water, making the water in the reservoir non-drinkable and unfit for use in most civil activities, as for example for use as firewater during freezing temperature, see also [3, 4].

5. Case study number 1: Utqiaġvik (formerly Barrow), Northern Alaska

5.1 Climate at Utqiaġvik

Utqiaġvik is the northernmost town in North America at 71 ºN. The population is about 4.500. The warm season in Utqiaġvik (Figure 2) starts in June and lasts to mid-September. During this period, the average daily highest temperature is 2 ºC. The average daily highest temperature is in July with 8 ºC [9]. In January, the average daily highest temperature is -21 ºC, temperatures down to – 40 ºC are not uncommon.

During the year, the sky is cloudy most of the time, partly clouded or mostly clear only 30% of the time in June. The climate is mostly dry with a maximum average monthly rainfall during July and August of 2-3 cm. During the winter, the monthly snowfall is in average 5 cm. Snow can be expected during the months September to May. The wind has an average velocity of 5 to 6 m/s year around [13].

Figure 2. Map showing Inupiaq language place names shows the city of Barrow as Utqiaġvik at the Iñupiat Heritage Centre. (Map prepared by Marc Lester / Alaska Dispatch News)

5.2 Fresh water reservoirs in Utqiaġvik.

In the area, there are many lakes and freshwater ponds, several of these are located very near to the coastline that is exposed to heavy erosion [14] and salt-water intrusion. The reservoir providing fresh water to the town, used to be the Imikpuk Lake, however, the lake is contaminated, and the Isatkoak

Lagoon presently provides the fresh water for the town (Figure 3), although this Lagoon is prone to seawater flooding in case of large storm surges [14]. It is located at the end of the airport runway.

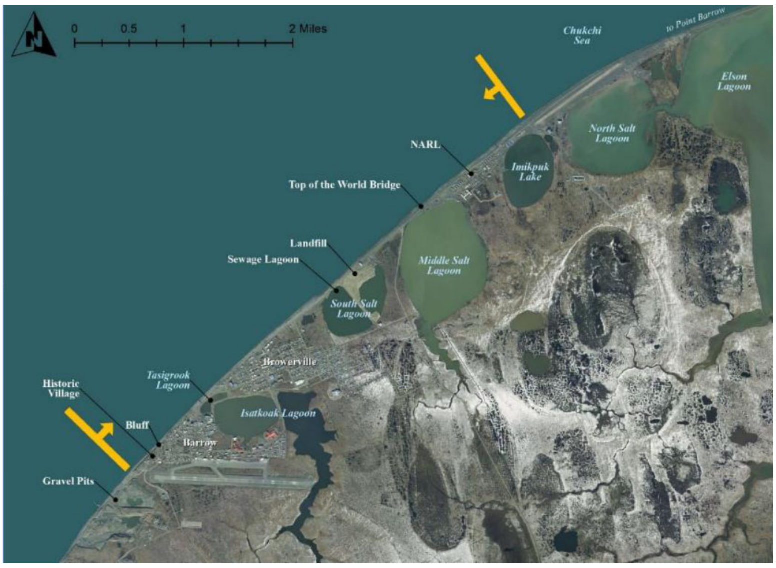

Figure 3. Satellite photo of Utqiaġvik (formerly Barrow), Northern Alaska. [14]. Note the location of the Isatkoak Lagoon providing drinking water to the town and the Imikpuk Lake previously providing the fresh water to the town.

The previous freshwater reservoir, the Imikpuk Lake was declared as unfit for drinking water as it was documented in 2017 that the levels of PFAS (per- and polyfluoroalkyl substances, released as a result of historical firefighting activities) exceeded the U.S. Environmental Protection Agency's (EPA) Lifetime Health Advisories (LHA). The contamination followed the response to two airplane crashes that occurred near Site 5 Airstrip in the 1970's [15]. The fresh water supply is a constant worry for the people living in the town and all efforts are made to keep the present drinking water reservoir free of contamination.

6. Case study number 2: Longyearbyen, Svalbard, Norway

6.1. Climate at Svalbard

6.1.1 Air Temperatures. Svalbard has an Arctic climate, but it has recently warmed significantly due to global warming. According to Norwegian Meteorological Institute, the average temperature in Longyearbyen during December, January, and February was -16° Celsius in the period 1961 to 1990. From 1991 to 2002, the temperature increased to -12 °C, which is 4 °C higher over the same period. In addition, the temperature has risen by 5°C in December and January in other parts of Svalbard [13]. It should be noted that the increase during the winter months is the highest. This will most likely lead to a severe impact on snow cover and the permafrost in the area as well as to provide more rain in future years.

6.1.2 Ground temperature at Svalbard. Svalbard has permafrost, but the ground temperature is rising. The graph below, Figure 4, shows the change in ground temperature in an area on Svalbard from 1998-2017 [16]. It shows a steady rise during the period. The temperature is measured at a depth of 10 m. Closer to the surface, it could be higher. When the temperature in the air increases, the ground temperature will increase even more. The measurements in the graph were taken in a cold area of the archipelago. In Longyearbyen, the temperature in the ground is higher than this [16]. This means that the permafrost in Longyearbyen in the future may be in jeopardy.

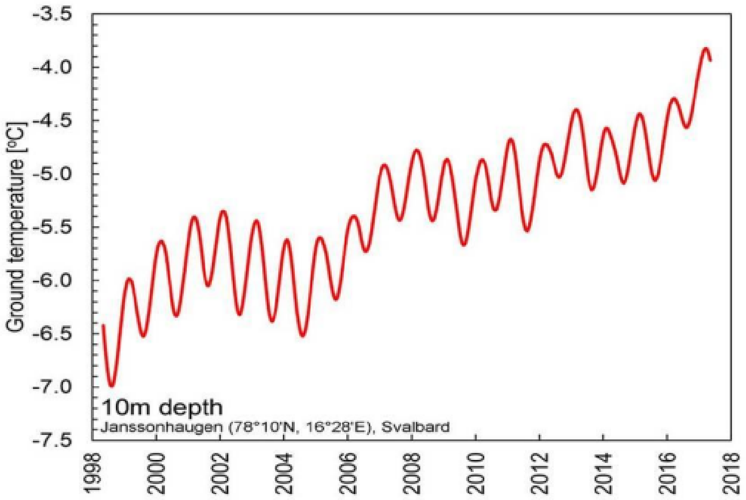

Figure 4. Ground temperature at Janssonhaugen Svalbard (near Longyearbyen) [17].

6.2 Fresh water availability

In Svalbard, freshwater is taken from Isdammen (see discussion below) during most of the year. However, during summer months, water is taken from the river running through the Longyearbyen valley and origination from the glaciers to the south of the valley. During winter, this river is frozen. The access to safe drinking water is under pressure [18, 19].

6.3 Isdammen (The Ice-dam reservoir)

Isdammen is located in Svalbard, east of Longyearbyen and is operated by the local government, Figures 5 and 6. The lake is around 2,5 km long and 0,6 km wide located at an elevation of 14 m above mean sea level. A 4 m high dam keeps the water in place. Its coordinates are 78° N and 15° E. According to the Norwegian Water Resources and Energy Directorate (NVE), the bottom of the lake is made of stone and earth and has an overflow of concrete [19]. There are numerous sources of water that lead to the lake. Some of the water supply comes from the Endalen watershed. Endalen watershed is composed of various elements, such as rainwater, snow, and ice melt. It also has a moderate mining presence, [20]. This is also true for other watersheds in the area. The lake is next to a cliff which also supplies it with melting water in addition to releasing more sediments into the water.

In 1960, the dam was created to provide Longyearbyen with more fresh water. Before this, the locals got some of their water from the watersheds leading to Isdammen and from other watersheds, [21]. The lake supplies the region with drinking water in winter, spring and autumn and is the town's only drinking water source in winter.

A road has also been constructed leading to the dam and beyond, Figure 7. At the outlet of the dam to the north, a pump house is built. The water is piped to nearby Longyearbyen. Instead of being buried underground, the pipeline is placed atop of the ground because of the permafrost [19]. A map showing Adventdalen in 1896 is added (Figure 8). This year was prior to the industrialization of Longyearbyen (prior to mining activities), and the map clearly shows a considerable loss of glaciers.

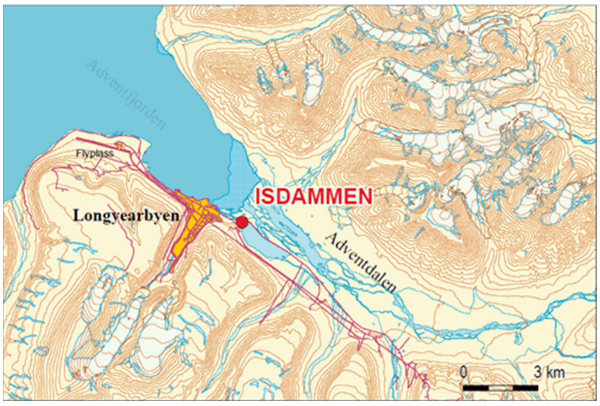

Figure 5. Location of Isdammen, Svalbard

Figure 6. Longyearbyen (to the right) and Isdammen (to the left). Photo by Helena Nynås, NVE

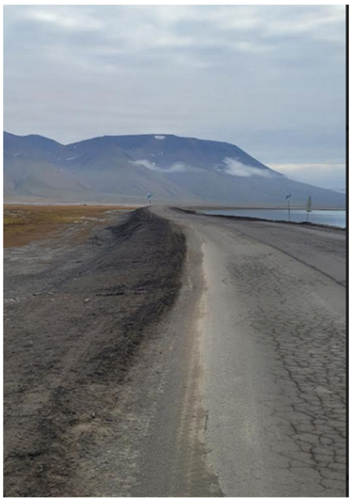

Figure 7. The road passing Isdammen (seen to the right). Photo: O. T. Gudmestad, August 2023.

Figure 8. Sketch map of part of Spitsbergen (the main island of the Svalbard Archipelago). From a survey of Sir W. Martin Conway, summer of 1896. (Map in Privat ownership). The map shows a considerable loss of glaciers compared with present glaciers, compare with Figure 5.

7. Qualitative risk analysis

7.1 Bow-tie diagram

A Bow-tie analysis has been conducted to identify causes and consequences, The causes of an (unwanted) event can be mitigated by prevention barriers/ controls, while the consequences of the event happening, can be reduced, or avoided by barriers/ controls providing mitigation or recovery, see Figure 9. It must be noted that there might be escalation factors influencing the barriers/controls to enhance the effects of the prevention barriers or to strengthening the mitigation and recovery controls.

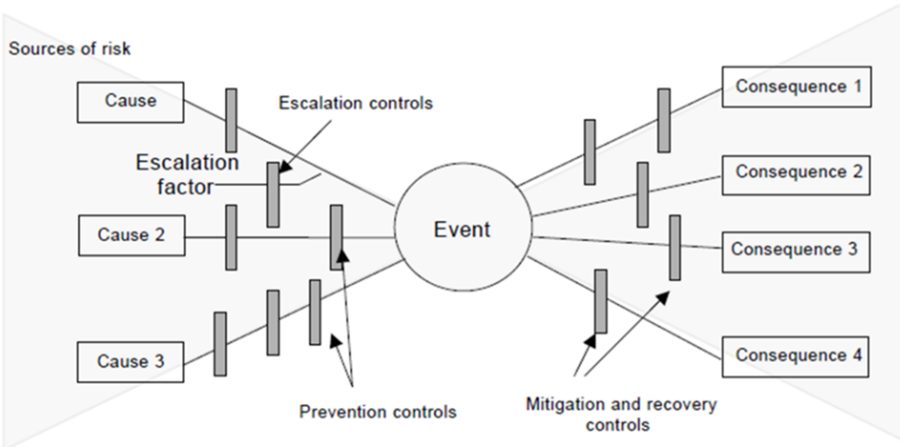

Figure 9. Basic elements of a bow-tie analysis

To analyse a bow-tie diagram, we need to identify the top event. In this case, it is “Degradation of drinking water sources in the Arctic,” See Figure 10. This event represents a serious issue and there are many causes that can lead to this event. In Section 7.2 causes and consequences are discussed as well as prevention and mitigation barriers. Figure 10 does not show any escalation controls; however, physical attention and daily control of the drinking water source represents a recommended control measure reducing the top event to occur and reducing the consequences of a top event.

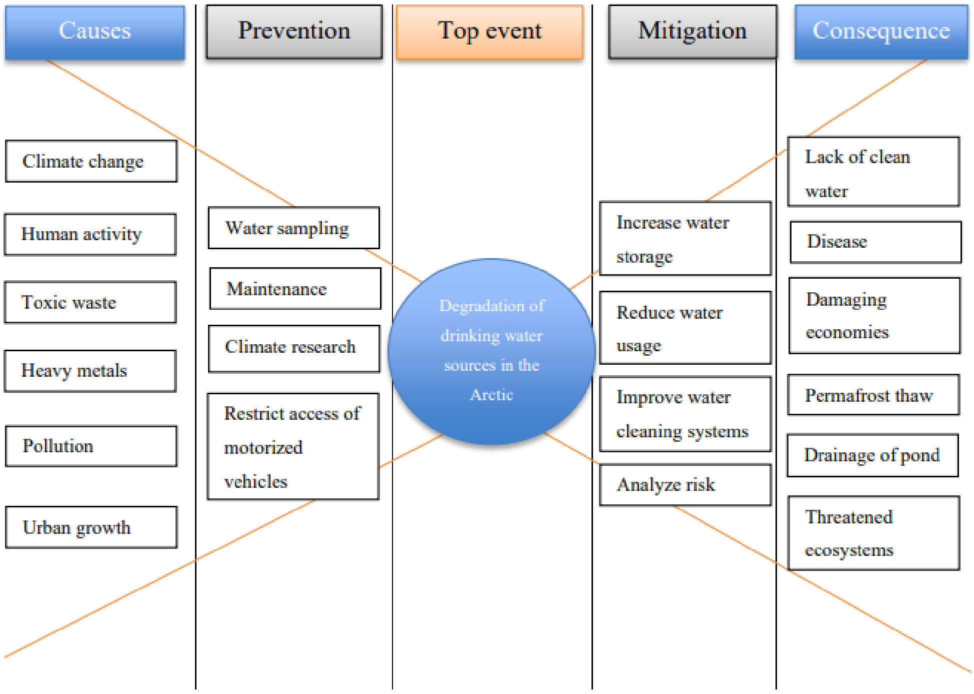

Figure 10. Bow-tie diagram of undesirable event "Degradation of drinking water sources in the Arctic."

7.2 The qualitative risk evaluation

7.2.1 Causes. The primary causes of degradation are climate change and human activity. The warming of the environment causes more snow and ice to melt and it heats up the permafrost. This causes more sediments to get into the water systems, some of which may be heavy metals that cause illness when consumed. In addition to this, when the permafrost is gone, the water may even drain away, [10], [22].

Humans impact areas where they stay. In general, we can think of pollution made by vehicles and different types of waste, from trash to factory waste products to construction waste, [23]. These pollutants may all enter the water. At Isdammen, there is a road right next to the reservoir, which can lead to emissions from cars and other vehicles to enter the water. All these factors can lead to negative consequences.

7.2.2 Consequences. The consequences are all negative, however some are more impactful than others. First, clean water may be a lacking resource in the Arctic, especially during winter. Although it is possible to melt snow and ice with heat to get water, it is energy consuming and not very efficient. That is why lack of a clean water resource can become a serious issue. Either if it is because of pollutants in the water or because there are insufficient volumes of water. Pollutants in the water may cause diseases and are costly to remove. The economy may take a toll from degrading drinking water. This can be through having to heat up snow/ice for water, having to import water or having to improve the water filtering systems or other parts of the water distributing infrastructure. Lastly, the ecosystems in the Arctic can be affected by the warmer weather and changes that can come from variations in snow cover and reduction of permafrost. The reduction of permafrost may be the most influential factor on how the water conditions are, and especially the amount of water. As seen before, in a lot of arctic regions, the permafrost ensures that the water does not drain away, [9]. A lot of arctic lakes are shallow [10]. Isdammen on Svalbard is around 4 meters deep, meaning it is susceptible to increased drain in the ground. Increased temperature will also increase the amount of water supplied to the lake from melting snow and ice, so there may become a balance between water supply and loss. It is uncertain how it will be in the future. The topography of the area is also something that can affect how much water is in the lakes. Isdammen has a cliff on one side and downward slope on the other side. Increased melting on the cliff-side will cause more sediments to enter the water, maybe making it murkier and shallower. There is also a fear that the cliff-side will become unstable and cause mudslides, [16]. The sea is also not far away. Having the sea nearby will affect how the permafrost melts, as the salt in the water reduces the heat needed to melt ice.

7.2.3 Prevention. To prevent some of the consequences will be difficult. Climate change has already started and the temperature has risen significantly in the Arctic. This means that there in a lot of Arctic regions will be thawing of permafrost, and lakes will be affected, [8, 10]. One thing that is done in order to try and prevent the consequences is climate research and other research, which gives us answers that can help reduce the speed of degradation and hopefully keep the lakes and water supply in good condition. In addition to this, water sampling is being done to monitor the condition of the water. This helps being ahead of the top event and seeing if the water's condition degrades. Isdammen is currently being monitored regularly [20]. Maintenance is also important, for instance on dams and other infrastructure, such as pipes and pumps. To help keep the water as fresh as possible, restricting the access of motorized vehicles is also an option. This is especially the case around Isdammen, where a road is right next to the lake. On Svalbard, a lot of people use snowmobiles. Right now, these are prohibited from driving on the lake, so some measures are in place. What can be done if these measures were not sufficient?

7.2.4 Mitigation. To mitigate the effect of the top event, there are some things that can be done. First, the water storage can be increased by building a higher dam. Higher temperatures will lead to more melting which in turn will lead to more water that can be stored. This is the case in many Arctic regions. One thing that can be done if there is water shortage is to reduce the amount of water used. This is at least doable in a short term, but if a place is going to grow, there should be an abundance of resources, including water. The water filtering system and other infrastructure can also be improved. At least in cases where the biggest issue is pollutants in the water. In some cases, the only thing you can do is monitor and analyse how the top event unfolds and try to mitigate the worst consequences. This is especially the case when we talk about permafrost thaw, which seems inevitable from global warming [24]. Because this is a relatively new phenomenon and we are only able to study the causes of it now, research must be done continually to know which consequences it will lead to. Change in snow cover and higher temperatures will make room for more biodiversity and a change in the biome growth, [25], [26]. The changing ecosystem will also be an unknown factor that needs to be monitored. If there is more plant life, maybe there will be more algae in the water that makes it undrinkable.

8. Conclusions

Drinking water in the Arctic is affected by many different sources. They can each cause different consequences, and some are easier to prevent and mitigate than others. Global warming and change in temperature are the hardest to do something with. It influences a lot of different conditions. It affects snow- and ice cover, precipitation and most importantly permafrost.

The permafrost has done a lot to make sure that the conditions in the ground in the Arctic has stayed relatively the same over thousands of years. Now, signs say that it is starting to thaw. This can have a large impact on water sources, either by causing more drainage, making more pollutants or sediments enter the water or make whole cliff-sides enter the water.

This can be the case at Isdammen, Svalbard, Norway. At Isdammen, there are already signs that the water contains pollutants. That is why monitoring and researching the area is important to prevent the water from becoming undrinkable. In Arctic areas in general, it is important to monitor drinking water supply and make sure that there is sufficient volume and of drinkable quality.

The situation in Utqiaġvik (formerly Barrow), Alaska is in addition complicated due to the erosion of the shoreline with probability of saltwater intrusion as well as the potential for contamination due to the closeness to the airstrip. How can we prevent the degradation of drinking water in the Arctic? First, improving infrastructure such as water filtering, pumps and dams are necessary if the degradation comes from increased amounts of pollutants in the water. More pollutants will enter with more melting snow and ice. If the degradation comes from reduced amounts of water, it is harder to prevent it. Improving the infrastructure can mitigate as well as prevent degradation. If one water source disappears or becomes unusable, there may be a need to consider other sources. As is the case in Longyearbyen, which in summer uses a different water source than in winter. If temperature increases, maybe the town will not need to rely on Isdammen as much in winter.

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