Challenges and solutions for water resources management in cold climates

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Summary
After discussing the concepts Water Resources Management and Cold Climate, the article focuses on freshwater resources in the Arctic and possible impacts of future climate changes on snow, water, ice and permafrost. The potential impact of future changes on the availability and quality of water resources, infrastructure and water uses is discussed; inter alia impacts on water supply, wastewater management, transportation systems, industry (mining, oil and gas) and hydropower. The article is based on recent synthesis reports and articles related to the report "Artic Climate Issues 2011: Changes in Artic Snow, Water, Ice and Permafrost - SWIPA issued by the "Arctic Monitoring and Assessment Programme (AMAP) in 2011 and reports and articles prepared for the coming updated SWIPA-issue to be presented in 2017.

Sammendrag
Artikkelen ble presentert som Keynote speech på European Water Association (EWA)´s konferanse om «Water Management: Challenges in cold climate» på Svalbard i juni 2016, hvor Norsk Vannforening var medarrangør. Artikkelen fokuserer på klimaendringenes virkning på integrert vannressursforvaltning i kaldt klima knyttet primært til ferskvannsressursene i kryosfæren; her definert som geografiske områder som i sesonger eller året rundt har snø, is eller frossen grunn og i samsvar med avgrensingen brukt av Arctic Monitoring Assessment Program (AMAP). Potensielle virkninger av klimaendringer for tilgjengelighet, kvalitet og bruk av ferskvann diskuteres; bla for vannforsyning, avløp, transport, industri (olje, gass og gruvevirksomhet) og vannkraft. Innholdet i artikkelen er i det alt vesentlige basert på synteserapporten *"Artic Climate Issues 2011: Changes in Artic Snow, Water, Ice and Permafrost – SWIPA"* utgitt av AMAP i 2011 samt senere rapporter og artikler som lå til grunn for den oppdaterte SWIPA-rapporten som ble presentert på utenriksministermøtet i Arktisk Råd i mai 2107.

Introduction
A much used definition (Global Water Partnership) of Water Resources Management (WRM), or Integrated Water Resources Management (IWRM), reads as follows: *"Integrated Water Resources Management - IWRM is a process, which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social well-fare in an equitable manner without compromising the sustainability of vital ecosystems".*

Thus IWRM concept addresses both land and water, and includes both freshwater and marine waters. However, as the main focus in this seminar will deal with freshwater issues – be it surface water or ground water-, "freshwater IWRM "will be in focus. However, necessary attention is given to the close interaction between marine and freshwater systems.

What do we mean with Cold Climate - and where?

Cold Climate can be defined in many ways; regions with mean annual temperatures below a certain value, north or south a certain latitude (Artic/Antarctic circles), or by subjective concepts like: "living in Italy I think you Norwegians live in a cold climate- "etc.

We chose to define cold climate similar to the definition of the "Cryosphere", which is the scientific term applied on that part of the Earth's surface that is seasonally or perennially frozen. It includes snow, frozen ground, ice on rivers and lakes.

Some elements of the cryosphere, such as the extent of snow, ice over water, and the dynamics of glaciers and ice streams vary greatly over short timescales (seasonally, or from year to year) and from place to place. Other aspects of the cryosphere, such as the extent of permafrost and large ice sheets, vary and change over decadal time scales and large areas.

Using the "Cryosphere" as a definition, we include the issues, problems and challenges we address at this seminar. Being at Svalbard, we chose to focus on the definitions of the Artic used by the Arctic Monitoring and Assessment Program AMAP- the scientific board of the international circumpolar Artic Council; figure 1. Two geographically defined areas are shown; a) the general delineation used by AMAP (2011), and b) the artic freshwater hydrological regime used in the Artic Freshwater Synthesis project (AMAP et al. 2016)

With focus on the Artic/Artic Freshwater Domain and the cryosphere, we do not address other regions with very cold climate such as mountainous areas further south etc. However, the issues and developments discussed are more or less relevant to all cryosphere areas.

In the Artic Cryosphere we are witnessing dramatic climate changes, and changes are predicted to continue and accelerate with dramatic impacts on ecosystems, natural resources, people and their livelihood, including infrastructure. What is the latest updated knowledge on these

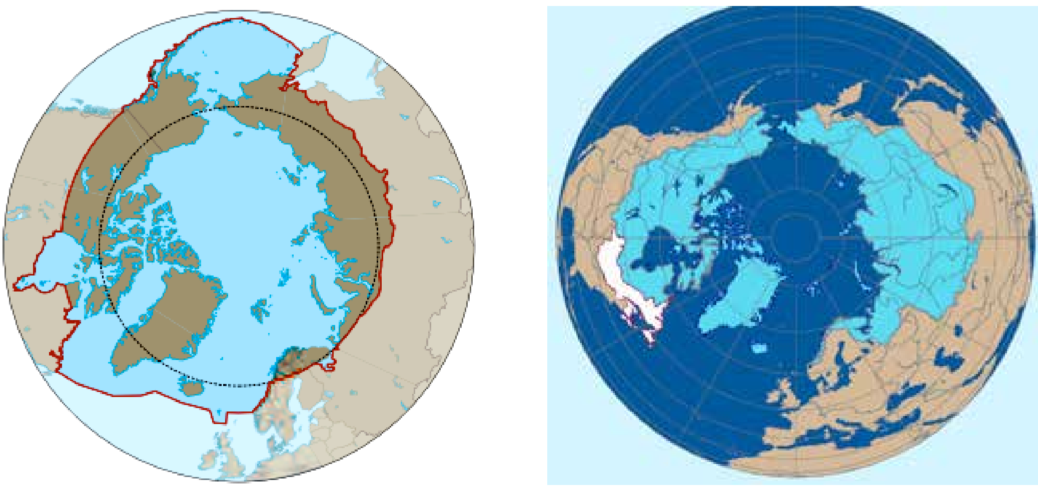

Figure 1. Geographical delineation for the Artic. a) The Artic as defined by AMAP and b) The Arctic Freshwater Domain*
**The "AMAP" definition essentially includes the terrestrial and marine areas north of the Arctic Circle (66¤32`N), north of 62 N in Asia and 60 N in North America modified to include marine areas north of the Aleutian chain, Hudson Bay and parts of the North Atlantic including the Labrador Sea. The Artic Freshwater Domain definition allows for a more complete understanding of how the Artic hydrological system operates.*

issues and how can we meet the challenges? Even if there are large knowledge gaps on crucial issues, decades of extensive international monitoring and research activities, including natural and social sciences, give us a good background.

Why and how is the Artic Cryosphere changing?

AMAP produces regularly assessment reports on important issues related to climate change in the Artic. A key theme is freshwater, and the last report "Snow, Water, Ice and Permafrost – (SWIPA)" was published in 2011 (AMAP, 2011). A new SWIPA report is in preparation and will be presented to the Artic Council early 2017. The key findings from the 2011 report are still representative (Lars Otto Reiertsen, Executive Secretary in AMAP, pers. communication) for the situation, however it will be highlighted that the future climate changes will happen even faster than earlier predicted. Furthermore, the next SWIPA report will also focus on impacts and necessary mitigation and adaptation measures if the Paris agreement on limiting the global temperature increase to 1.5 and 2C is to be achieved.

11 of the 15 key findings from AMAP`s 2011 assessment report "Snow, Water, Ice and Permafrost – (SWIPA)" (AMAP, 2011) provide a broad and general state of the art as of 2011:

1. The past six years (2005–2010) have been the warmest period ever recorded in the Arctic. Higher surface air temperatures are driving changes in the cryosphere.
2. There is evidence that two components of the Arctic cryosphere – snow and sea ice – are interacting with the climate system to accelerate warming.
3. The extent and duration of snow cover and sea ice have decreased across the Arctic. Temperatures in the permafrost have risen by up to 2 °C. The southern limit of permafrost has moved northward in Russia and Canada.
4. The largest and most permanent bodies of ice in the Arctic – multiyear sea ice, mountain glaciers, ice caps and the Greenland Ice Sheet – have all been declining faster since 2000 than they did in the previous decade.
5. Model projections reported by the Intergovernmental Panel on Climate Change (IPCC) in 2007 underestimated the rates of change now observed in sea ice.
6. Maximum snow depth is expected to increase over many areas by 2050, with greatest increases over Siberia. Despite this, average snow cover duration is projected to decline by up to 20% by 2050.
7. The Arctic Ocean is projected to become nearly ice-free in summer within this century, likely within the next thirty to forty years.
8. Changes in the cryosphere cause fundamental changes to the characteristics of Arctic ecosystems and in some cases loss of entire habitats. This has consequences for people who receive benefits from Arctic ecosystems.
9. The observed and expected future changes to the Arctic cryosphere impact Arctic society on many levels. There are challenges particularly for local communities and traditional ways of life. There are also new opportunities.
10. Transport options and access to resources are radically changed by differences in the distribution and seasonal occurrence of snow, water, ice and permafrost in the Arctic. This affects both daily living and commercial activities.
11. Artic infrastructure faces increased risks of damage due to changes in the cryosphere particularly the loss of permafrost and land-fast sea ice.

Updated knowledge on the Artic Freshwater System

An interdisciplinary research project "The Artic Freshwater Synthesis" project has recently - March 2016- presented a report "Artic Freshwater System in a Changing Climate" (AMAP et al, 2016) which is a review of the latest relevant research findings on the artic freshwater systems. The report will provide important input to AMAPs next 2016 SWIPA report. The report comprises six chapters, covering the atmosphere, oceans, terrestrial hydrology, ecosystems, Arctic resources/infrastructure, and modeling.

Some extracted and quoted "water management-relevant" highlights from the report emphasize that the Artic freshwater system is extremely important for the region is illustrated by the fact that the Arctic Ocean contains just 1% of the world's ocean water. However, the rivers flowing into it from Norther American and Eurasian landmasses accounts for 10 % of the total flow from the worlds rivers. A huge volume of freshwater mixes with saltwater to form a less saline layer above denser saltwater. This stratification has several effects of which the ability to freeze and produce ice is the most important; the "albedo" effect, the ability to reflect solar radiation helps to cool the water.

The global warming in the Artic, temperatures are increasing twice the global average, is increasing the intensity of the Arctic freshwater system. Warmer temperatures puts more energy into the hydrological cycle, and a warmer atmosphere can hold more water and enables more transport of moisture from lower latitudes.

This is contributing to increased precipitation in the Arctic, falling either as rain or snow. In many parts of the region, the proportion of precipitation that falls as rain has increased, and the period of snow-cover has become shorter. Arctic river flow has increased and the timing of peak flows and river ice cover is changing, reflecting the altered patterns of precipitation and snow- and ice-melt. And the area of permafrost soils (ground that remains frozen all year around) is shrinking with warming as well as areas with seasonal snow and/or ice cover.

Changes to the water cycle with increasing precipitation and thawing permafrost are changing Arctic landscapes and ecosystems. Water courses and patterns of lakes and wetlands change; thawing permafrost can create small lakes, whereas in other areas it is allowing water to drain away, causing existing ponds and lakes to dry out. Deeper layer of soil above permafrost allow shrubs and forests to move further north.

The Arctic ecosystems are altered with the changes; some species are thriving, others will struggle. The timing of seasons can be particularly challenging to species to adapt to, for example migrating birds. The changes in the freshwater systems coupled with many ecological feedback processes, are likely to cause surprising and unexpected reorganizations of ecosystems.

The coastline has a particularly important role in the Arctic and perhaps the most significant changes to the Arctic landscape are taking place where the land meets the sea and where the large amounts of freshwater and sediments carried by large rivers enter the Arctic Ocean. The coastal zone is particularly important to

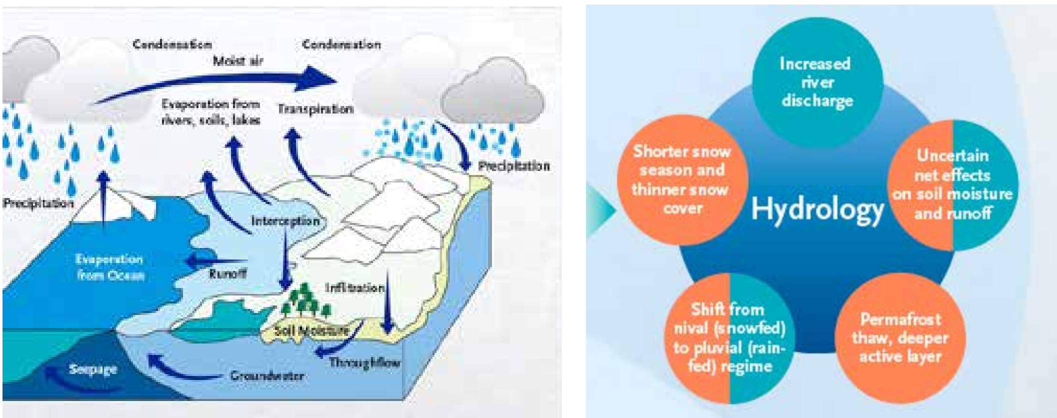

Figure 2. The hydrological cycle intensity increases with warming: more precipitation, more rain and less snow. Illustration of climate warming impacts on hydrology. (AMAP et al., 2016)

humans in the Arctic, as it is where they typically live, work and hunt. Connecting the terrestrial and marine ecosystems is a unique Arctic environment, known as the Riverine Coastal Domain; a zone that extends offshore between 1 and 20 kilometers, and that is characterized by low salinity waters in the upper 10 to 20 meters. The zone is important for marine life to disperse and migrate; sediments and nutrients are available from increasing run-off from rivers and lands having profound both positive and negative effects on the ecosystems.

The Arctic provides "ecosystem services" which will be impacted by the changes. Key services are food, water, pollution and contaminants breakdown, transportation, and tourism.

The two most obvious benefits that ecosystems provide to humans is the provision of food and water. Two of the largest commercial fisheries are forum in the Barents and Bering seas. Indigenous people rely on traditional wild-caught foods; fish and mammals. Changes to ecosystems can reduce the value of ecosystems services; for example: increased inputs of nutrients caused by thawing permafrost and enhanced flows of water could lead to eutrophication in freshwater systems with algae blooms that reduce water quality, crowd out species and could damage a drinking water supply source. Thawing permafrost and changes in precipitation pattern can damage water infrastructure and reduce the permafrost`s ability to contain and isolate waste and wastewater

Breakdown of pollutants and contaminants is also an "ecosystem service" However, a more intense hydrological cycle will increase the rate at which contaminants such as mercury, persistent organic pollutants such as DDT, and radioactive particles move through the environment. With warmer climate ice-captured contaminants could leach into wetlands or rivers.

Permafrost helps people move around. Transport corridors on frozen rivers and permafrost, - ice roads-; provide important means of supplying remote communities during the winter months. Indigenous people rely on ice to move around and reach remote hunting grounds. Declines in permafrost and shorter periods of winter ice reduce the amount of time these transport routes can be used. However, higher air and water temperatures mean that rivers will be navigable for more of the year. Open water transportation on rivers and lakes is one of the main methods for transporting goods in Russia and is also important in norther Canada and Alaska. Climate changes increases number of ice-free days, but more run-off has resulted in more need for dredging. Commercial sea transports between continents through the North-West and North- East passages is near in the future.

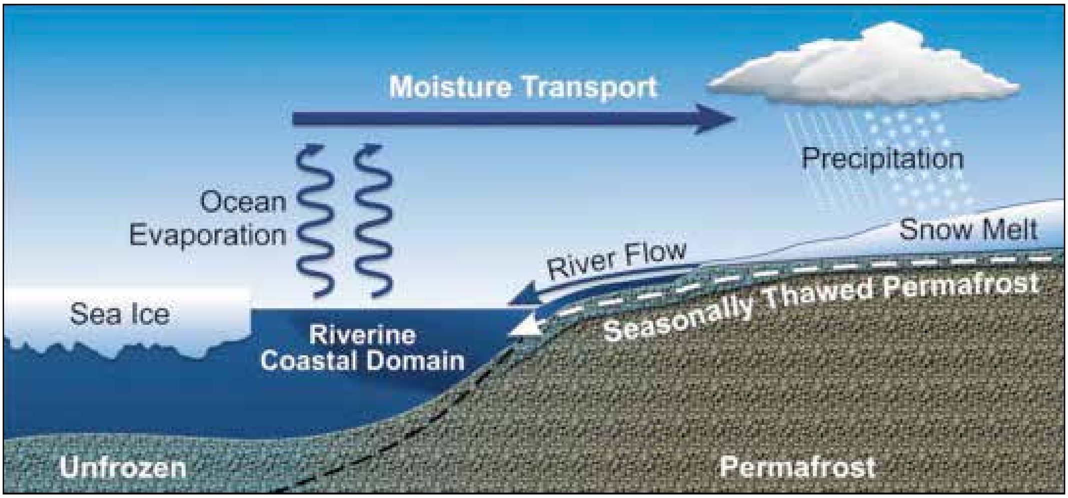

Figure 3. Illustration Coastal Zone- Riverine Coastal Domain. (AMAP et al., 2016)

The Arctic environment is very attractive to tourists, and ecotourism has grown rapidly in recent years. Reduced summer sea-ice offers easier access for cruise ships, but this benefit may be partly offset by possible declines in the populations of species tourists want to see.

Changes in Artic Freshwater Systems and Implications for Economy and Water Management

The numerous "snow, ice, water permafrost" changes in the Arctic freshwater system have been summed up in the article "Changes to freshwater systems affecting Arctic infrastructure and natural resources" (Instanes et al. 2015).

Increased precipitation means improved freshwater availability. Type of precipitation will change (less snow, more rain), as well as seasonal distribution, timing and rate of snowmelt. Increased winter and spring temperatures produce earlier and more rapid snowmelt events with more compressed run-off period with higher peak flows and danger of floods. More rainfall can increase risk for landslides in permafrost regions.

However, in permafrost regions the availability of freshwater may be limited during periods of summer drought.

These changes will have important_positive and negative implications for the region's economy. The Arctic is home to some 4 million people, and with the warming more people are likely to live and work in the region. Most activities including exploitation of natural resources will become easier for which a reliable well-distributed water source is of paramount importance. Freshwater changes will represent both threats and challenges, but also opportunities.

The availability of water resources is the departure point for elaboration on the impact of climate changes for specific water related activities such as water infrastructure, transportation, mining, oil and gas exploitation and hydroelectric power.

Arctic nations have a low water stress (annual freshwater demand in a river basin compared to the annual average water available in the basin) compared to regions farther south. From a freshwater resource point of view, Arctic nations may benefit from an increase in the total available water supply.

It could be mentioned that a projected increase in high-latitude precipitation and subsequent increase in total freshwater system volume, together with increased occurrence of droughts in southern regions, will increase the importance of the Arctic as a source of water resource for southern population centers. (South–North Water Diversion Project in China, transferal to west United States and to dry regions of Russia)

The challenges for municipalities – water supply and wastewater management infrastructure will be focused in detail at the conference; thus only a few overarching items will be focused in this article.

- Among the freshwater sources in remote regions (surface water, ground water, and melting of ice and snow) groundwater is usually a good source but can be more limited than surface water. In areas with continuous and discontinuous permafrost the groundwater must be extracted from below the frozen.
- Groundwater from the active layer and permafrost layer is usually not considered a good drinking water source for human consumption due to a relatively high concentration of impurities. This is also the case with water supply under the permafrost layer. Water treatment may be needed. Extraction of groundwater in permafrost regions is costly (drilling and operation of wells).
- Surface water from lakes and streams is common in northern areas. Water quality in winter is generally good because of limited sediment transport and organic content.
- In the summer, water treatment may be necessary due to the high content of minerals and organic matter. The freezing process expels impurities and influences the remaining unfrozen water. Storage capacity is also an important; shallow lakes and streams often freeze to the bottom.

- Increased air temperatures resulting in increase in active layer thickness and permafrost temperature may increase the risk of contamination of freshwater resources associated with municipal and industrial waste disposal.
- All water supply and wastewater infrastructure is stressed by extreme events and warming permafrost resulting in higher repair and maintenance cost.
- Wastewater treatment processes in lagoons will in the Arctic benefit from increased temperatures.

There is increasing interest in the enormous wealth of minerals, oil and gas that is present in the Arctic. Alaska and Arctic Russia are already important sources of oil and gas. Norway produces oil/and gas outside the coast of Finnmark at 71degrees N. and will open for test drilling in the Norwegian sector in the Barents Sea. And Greenland contains substantial deposits of uranium and other minerals.

Many of the processes involved use large amounts of freshwater, and it is likely that more water will be available. Further warmer climate will make it easier to extract and get access to the resources. However the need for ice-roads for transport of heavy machinery meet challenges as well as all activities impacted by permafrost changes (constructions, building of pipelines, containment of waste).

Hydropower (HP) represents approximately 64% of the installed capacity in renewable energy worldwide. 95% of Norway`s electricity, more than half of Canada`s, and nearly half of Sweden`s, is produced by HP. Figure 4 show HP stations in the northern hemisphere. A significant portion of the water used for HP -production in these countries originates from Arctic regions. Observe the general difference in installation size between Scandinavia and Canada/USA/Russia.

Changes to the water available; the amount variability etc. have a large impact on HP production and on the economies. In HP intensive

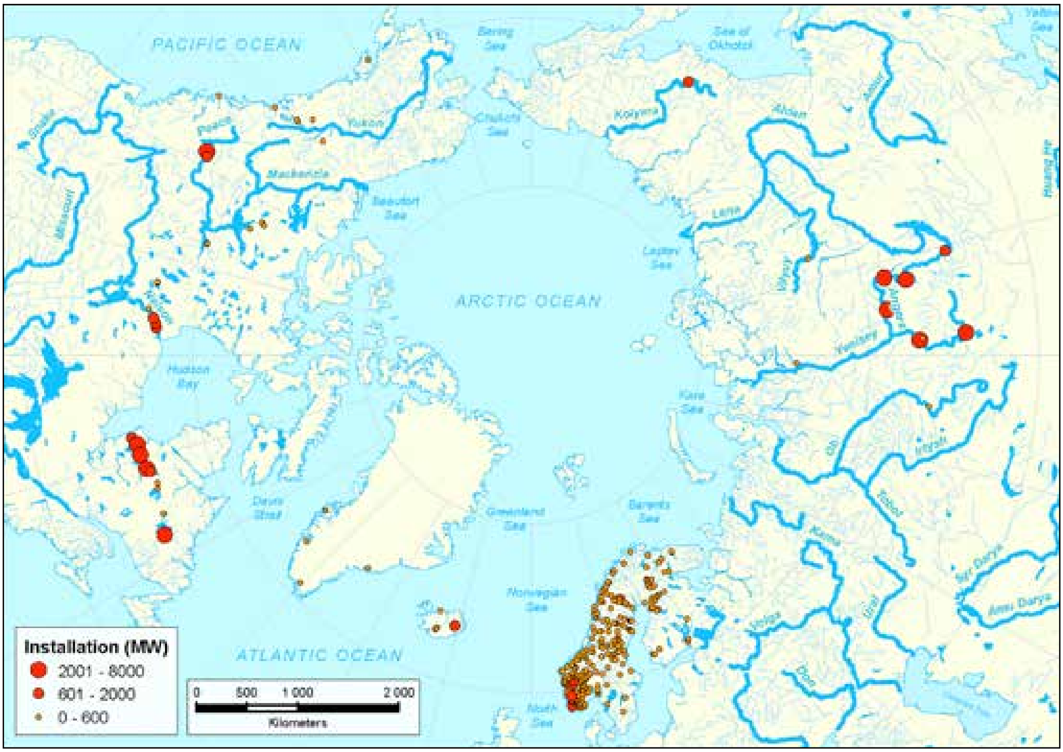

Figure 4. Hydropower installations in the Arctic (Instanes et al.).

countries there is a strong correlation between water shortage and high-energy costs. In Norway, the price of electricity in a dry year is much higher than in a wet year. In wet years inexpensive hydropower determines a low market price. In drier years, more expensive energy sources such as coal and gas set the price of the electrical power supply offered on the market.

The Nordic countries, - (except Denmark), are sensitive to long-term variations in streamflow. Future hydrological will require new investments and design of operational and management practices in HP plants. Consequently reliable projections of future variations in streamflow are much in demand.

As an example of "looking into the HP crystal bowl"; - the Norwegian Water Resources and Energy Directorate –NVE (NVE, 2015) has recently evaluated the effects on future HP in Norway based on selected climate change scenarios. Some of the key findings:

Increased run off expands the hydropower potential and production will increase in existing plants. The greatest increase will be in areas with much regulated power generation as the runoff also increases most in these regions of Norway. The run-off will be more distributed over the year; as more precipitation will come as rain instead snow. However, flood loss will increase as the HP infrastructure will not be able to handle the large increase in runoff during autumn. There will be less seasonal variation in energy prices as smoother inflow contributes to the seasonal price fluctuations reduced. Reduced winter consumption due to temperature increase, increasing relatively more in the winter, which can lower power demand in the cold season.

Instanes et al. refers to several estimates for HP production based on different climate scenarios and different approaches. Some illustrating predictions: In the Nordic countries the increased water supply is estimated to 12 % in 2021-2050 compared to 1961-1990. In Norway an increase in production of 20 TWh in existing plants is estimated. Also in Sweden studies indicate an increase of 10-15 % flow increase in the northern part. However, further south in Sweden inflow and HP production is expected to decrease. In general, available water and HP production will increase in the Arctic, but decrease further south in Europe; the decrease in southern Europe will be significant.

The potential for more HP in the Arctic could create economic opportunities for the region. Small-scale hydroelectric production could be developed in areas that previously have not been feasible from a technological and economical point of view. However, the changing runoff patterns including floods can damage HP infrastructure. Knowledge on future water flows is very import to protect existing plants and for the planning of new HP- plants.

Knowledge gaps and recommendations

The AFS report (AMAP et al. 2016) draws conclusions on knowledge gaps and presents recommendations for policymakers. A few highlights as to knowledge gaps:

There is a need for more extensive and accurate observations; and as to freshwater, knowledge of all aspects of the hydrological circle including water flows and waterborne material flows are in great demand. Specifically, such knowledge is restricted by limited surface water monitoring.

Knowledge is needed of interactions among and between ecosystems, along with improved predictive models of ecosystem responses to alterations in water-, snow and ice-, and atmosphere-related drivers.

As to resources for water management resources, there is insufficient water-related information on consumption, irrigation, flow rates and the impact of climate change on water resources. The knowledge of impacts and of climate change on water quality and ground water are insufficient for adequate water resource management.

The AFS report recommends policymakers to consider inter alia further research on key processes and linkages between key processes, facilitate deeper understanding of the consequences of a more intense freshwater cycle, promote work to better understand key socio-economic consequences and develop tools to adapt to changes, continue to support education etc. One recommendation deserves in the context of this conference to be quoted directly:

"Providing additional resources to improve access to safe drinking water and waste treatment facilities for smaller communities in the Arctic".

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