Chapter 17
Water Information and Water Security in the Arctic

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Abstract Water is common to many environmental changes that are currently observed in the Arctic. To manage environmental change, and related water security challenges that are rising in the Arctic, adequate water information and monitoring is critical. Although water information systems have been deteriorating in the Arctic, there are still opportunities to combine existing data to inform policy decisions on how to manage water security. Furthermore, implementing a set of water security indicators can help identify areas of concern within the region. However, accessible climate change information is not always relevant for the scales of policymaking. In addition, improved representation of water on land in climate models is needed to better inform adaptation.

Keywords Hydrological monitoring • Environmental information • Arctic climate change • Water security • Water pollution

17.1 Introduction

The Arctic region is currently undergoing a series of rapid changes. Climate change is perhaps the most recognized of these, but socio-ecological, political and economic factors are also transforming at a rapid pace. These changes present the people residing in the Arctic, and their activities in the region, with a number of challenges.

Water is a central component in many of the environmental changes in the Arctic (Vörösmarty et al. 2001; Bring and Destouni 2014). For instance, the effects of climate change often manifest themselves through changes in the water system. Examples include increasing runoff in Arctic rivers (Peterson et al. 2002, 2006); increasing precipitation (Rawlins et al. 2010), although precipitation increases have generally been smaller than discharge increases (Bring and Destouni 2011), indicating a potential contribution of stored water or permafrost thaw; increasing mass loss of Arctic glaciers, with concurrent increases in both glacier and river runoff

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(Dyurgerov et al. 2010); and changing Arctic lakes (Smith et al. 2005; Karlsson et al. 2012, 2014).

One of the fundamental needs for managing these large-scale environmental changes is adequate and relevant water information. The importance of monitoring and observations, as a fundamental source of information about the state and change of the environment, has also been identified by the International Council of Scientific Unions as one of five "Grand Challenges" for science in the present decade (ICSU 2010; Reid et al. 2010).

Another major challenge for people and livelihoods in the Arctic will be to ensure an adequate and sustainable management and use of water and water resources (White et al. 2007; Evengard et al. 2011). In this chapter, we will highlight the critical role of water information, with a specific focus on water and water security in the Arctic, for managing change. We begin the chapter with defining the scope of the Arctic region in the context of water information and security.

17.2 Definitions

17.2.1 The Arctic

Definitions of the spatial extent of "the Arctic" may vary, depending on the context. In many cases, the 10° July isotherm provides a clear delineation of the relatively severe conditions that characterize the high Arctic. Alternatively, from a strictly geographical perspective, the 60°N latitude, or the Arctic Circle at 67.5°N, are sometimes used to constrain the northern polar region.

From a surface water perspective, however, the natural unit of investigation, and therefore of delineation, is the physical drainage basin. A drainage basin may be defined as the area upstream of a point, or shoreline of a water body (lake or sea), that contributes with surface runoff to that point or shoreline. A natural definition of the Arctic from this hydrological perspective is illustrated in Fig. 17.1, with all land draining to the Arctic Ocean and its adjacent seas, including major rivers.

From the figure, it is clear that a definition starting from the perspective of water resources extends far outside the area considered in the definitions based on climatic or strictly geographical boundaries outlined above. As a corollary, the Arctic, from a surface water perspective, is a very diverse region that comprises physical and socio-ecological environments not commonly seen as typically Arctic.

To collect and use information on water, be it just for a small catchment or a major drainage basin the size of the largest Arctic rivers, governments operate observation systems that monitor various parameters of the water system. These networks of monitoring stations provide information that is critical to water management, including management of water security.

Fig. 17.1 The land area draining to the Arctic Ocean and its adjacent seas. Major rivers are shown in *blue*

17.2.2 Water Security

Although the Arctic is not commonly perceived as a region where access to reliable freshwater would pose any problem to people and users in the region, several studies have highlighted that the particular circumstances in the Arctic in fact give rise to serious water security problems. We will return to these later, but first we briefly discuss the concept of water security.

The term "water security" has increased rapidly in prevalence in the academic literature over the last decade (Cook and Bakker 2012). Initially, it appeared more often in the context of military security, and security of human society, but today it is discussed in a wide range of academic disciplines and policy contexts. The broader use of water security as an integrated aspect of adequate water provisioning for all aspects of society, relating to its various uses across sectors and scales, is in line with our use of the term in this text.

The increasing focus on water security from a linked systems perspective is also in line with a more integrated approach to investigating the impacts of climate change on human society. For instance, initial work on impacts and adaptation by the Intergovernmental Panel on Climate Change (IPCC) had a more restricted approach to water security, and focused largely on direct impacts of increasing temperatures or changed precipitation on yields of various crops (Parry et al. 1990). Such direct biophysical links on the plant level have been relatively well studied in agricultural sciences, not the least in efforts to understand how to improve yields, and it was therefore possible to get a first-order picture of impacts by synthesizing such studies.

In recent years, climate research has changed emphasis to instead focus more on systems effects, in several ways. In terms of biogeophysical systems, research now puts greater emphasis on the landscape *effects* of precipitation changes, as the latter do not translate directly to changes in runoff, soil moisture or other critical components of the land-water system. Examples include studies on linked precipitation-runoff changes, also for the Arctic (Rawlins et al. 2010; Bring and Destouni 2011), and soil moisture changes (Destouni and Verrot 2014). Furthermore, evidence indicates that effects of land-use change and other human modifications of the land-water cycle have a strong influence on the regional partitioning between runoff and evapotranspiration (Destouni et al. 2013), and thus also on water availability in the landscape. These studies have illustrated the importance of explicitly considering the land-water system, and its propagating and transforming effects, when studying how climate change will affect human societies.

Further to these coupled physical changes, policy-oriented climate research has also shifted emphasis from investigating the local impacts of biogeophysical changes on crop yields, whether such studies adequately consider the coupled land-water system or not, to instead focus on the end effects on human societies (Porter et al. 2014). This means that greater importance is placed on identifying the actual food and water security of humans, which implies that the coupled context of food production and consumption must be considered. Food security also naturally incorporates water itself, as a foodstuff in its own right.

17.3 Water Security in an Arctic Context

As noted above, a water security approach has only relatively recently become established as a research framework, and investigations of the particular situation in the Arctic have been relatively limited in number.

White et al. (2007) investigated a number of water security challenges in the Arctic, with an emphasis on indigenous Arctic communities at high latitudes. As in other parts of the world, people tend to settle close to water also in the Arctic, and the hydrological setting of the settlements then determines the resilience of the community. Among other things, White et al. (2007) pointed out that a changing climate will most likely have effects on the permafrost underlying many northern communities. Other research has indicated that permafrost thaw may change flow pathways (Bosson et al. 2013), for example by instigating drainage or creation of thermokarst lakes, depending on stage in the thaw development (Smith et al. 2005; Karlsson et al. 2012, 2014). Such decreased availability of surface water may influence the reliability of water supply for Arctic communities. White et al. (2007) noted that efforts to draw on groundwater resources in the Arctic, in cases of attempting to replace surface water resources, have been met with disappointment, with problems including frozen soil and saline water.

In the White et al. (2007) study, water security was analyzed in conjunction with food security. This coupling between food and water security takes a variety of forms depending on the context. In general, the coupling is closely related to the share of market-based foods consumed – with a larger share of market-based foods, the supply of food itself is mostly disconnected from the local issue of water security. In contrast, water security is impossible to disconnect from the local water supply situation, as transportation of freshwater over large distances is prohibitively difficult and costly. At the same time, the *ability* to purchase foods on the market is likely strongly connected to both local food and water security, as the ability to produce local goods and services in demand in the market is often an important source of income for indigenous communities. These local goods and services then, in turn, likely depend strongly on local water and food security.

The water security context in the Arctic differs markedly with the various types of societies and ecosystems in the basin. In the circumpolar far north, indigenous communities face challenges as those described above. In modern settlements and larger cities, some challenges may be similar, such as ability to secure a sufficient supply of surface water, due to similar physical constraints, whereas others, such as the ability to buy food on the market, and access to infrastructure and transportation, are likely different.

Further south in the basin, the climate is mostly milder, and water availability is, in general, greater, although competition between various sectors is also greater, with a greater intensity of hydropower, agriculture, forestry, mining and industry. Following from this, the absolute levels of pollution from wastewater, transportation and production are greater in southern basins, even though the relative increase in pollution levels for the very pristine areas in the far north may be larger.

Risks related to metal pollution are currently increasing in the Arctic due to intensified mining activities. In addition to Alaskan, Canadian and Russian mining, there are considerable mining booms in the southern regions of the Arctic, for instance with mining of gold, silver, copper and coal in northern Mongolia (Chalov et al. 2012; Thorslund et al. 2012). Over 750 companies are presently involved in Mongolia alone, and a common practice is placer mining, which implies that alluvial deposits are mined in, or near rivers. Metal-rich sediments can then be released back to the rivers, where they can travel considerable distances in suspension. Due to changing ambient conditions in downstream Arctic environments, metals that have been transported with the sediments may dissolve into water and thereby become more bioavailable (Chalov et al. 2014; Thorslund et al. 2012). The large Arctic river Yenisei and the well-known Lake Baikal are both located downstream of northern Mongolia's mining region, and are additionally affected by Russian mining activities. Notably, metals have been shown to accumulate in biota of Lake Baikal, reflecting water quality issues despite the very large volume of the lake.

More generally, communities in regions subject to decreasing surface water availability – due to decreased runoff or water quality – will have to increasingly rely on groundwater resources. This is already a main issue in Central Asia, where an increasing number of people are subject to considerable health risks as they have to use contaminated groundwater as drinking water source when their main river systems dry up (Törnqvist et al. 2011). In the Arctic, groundwater resources are relatively inaccessible due to permafrost, as mentioned earlier, which lowers the water security. Furthermore, permafrost thaw may actually have adverse effects on groundwater quality in Arctic communities, since sewage infiltration may increase into water systems that supply drinking water (Smith et al. 2014).

Atmospheric deposition of hydrocarbons, including persistent organic pollutants (POPs), is considerable in the Arctic due to condensation of POPs that have volatilized from contaminated areas in warmer regions of the world. A main problem with the presence of POPs in the Arctic environment is that they are known to bioaccumulate in local food chains. In particular, in Alaska and northern Scandinavia, POPs have accumulated over time in glaciers and can be released to downstream water recipients as a result of increased glacier melt from global warming (Schindler and Smol 2006). In addition, intensified human activities in the Arctic means that its water resources are under increasing risk of contamination from accidental fuel spills related to snowmobiles, helicopters, military installations, pipelines, and damaged storage tanks.

Climate change poses an additional challenge to Arctic communities and cities. For the small communities, a ready supply of liquid freshwater is today often limited to a few months of the year. Although increased temperatures would allow water to remain liquid for a larger share of the year, other changes imply that water availability may in fact decrease. For instance, temperature increases in other northern regions have been linked to increasing evapotranspiration, in turn contributing to declining water content in the soil. As evident from the map in Fig. 17.2, large portions of the near-coastal Arctic can be considered polar deserts, with annual runoff below 50 mm, and for these regions, a declining water content in the soil would potentially contribute to small rivers and streams completely drying up during dry months.

17.4 The Water Information Challenge

The Arctic is a remote region, and for all Arctic states, a relatively small proportion of their populations live in the region. Despite the remoteness and sparse population, interest in the Arctic has recently increased markedly, with several states and

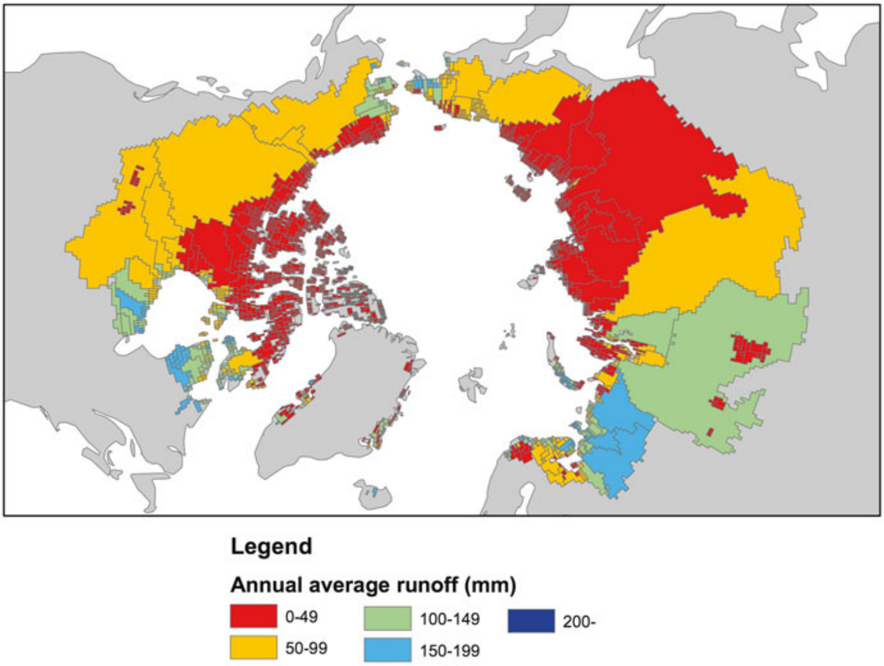

Fig. 17.2 Average annual surface water runoff in Arctic drainage basins (Data compiled from the climate data archive of Willmott and Matsuura (http://climate.geog.udel.edu/~climate/) for the period 1961–1990)

multilateral organizations formulating Arctic policies where none existed before (e.g., Sweden, Finland, and the European Union). Several factors contribute to this development: increasing accessibility due to declining extent of sea ice, increasing importance from a resource perspective, and as a corollary, from a military and political perspective. All these factors fundamentally arise from the effects of climate change in the region, which in turn has also contributed to put the region more in a global research spotlight. This increasing interest also implies a greater need for information, to guide both scientists, communities, industry and policymakers.

Water information is a fundamental requirement for adequate understanding and management of the water security situation, for any given region, country or community. First, information systems should allow continuous observation of the surface water system, so that its functioning and dynamics can be studied and understood. Secondly, continuous monitoring allows detection of any changes to the land water system (i.e., the coupled surface and groundwater system), so that this detection does not become erratic and unsystematic. Thirdly, in order to manage the adaptation to changes, a continuous monitoring allows for following up on any actions taken, evaluating the outcome, and adjusting any applied measures accordingly.

Although the need for information to understand the water system can be perceived as a pure basic science, it is in fact difficult to establish a strict hierarchy between the three uses of water information systems outlined above. To begin with, the understanding of the land water system is important on several levels. As a fundamental component in the surrounding environment, water propagates changes across the landscape, and between different systems in the biosphere, such as the troposphere, the shallow soil zone, rivers, lakes, and oceans. Observations of the land water system help develop the physical, biogeochemical and socioeconomic understanding and modeling that is used to both describe and project processes in the environment.

This knowledge, however, is also required for applied science and to resolve societal challenges, such as allocation of water for various uses, formulation of strategies for adaptation to climate change, and enforcement of environmental legislation. Misjudged perceptions about the functioning of the land water system may lead to policy decisions that are inefficient or even encourage counterproductive measures. For example, the design of engineering works to withstand given return floods may need to be changed with a changing land water system, but without observations, neither the understanding, nor the change detection or evaluation of measures is possible.

Despite the importance of information, the need for observations and observation capacity is often not considered explicitly. A sign of this is that the state of continuously operated monitoring systems that convey information on the status of the water system in the Arctic has deteriorated in recent decades. Several studies have highlighted this unfortunate development (e.g., Lammers et al. 2001; Vörösmarty et al. 2002; Hannerz 2008). Initially, most studies placed an emphasis on water quantity monitoring, but subsequently, other studies have revealed even greater shortcomings in water quality monitoring (e.g. Holmes et al. 2000, 2002; Zhulidov et al. 2003). The first integrated assessment of both water quantity and quality monitoring was presented by Bring and Destouni (2009), who also pointed out some critical areas where improved monitoring is needed.

17.4.1 Synthesizing Water Information and Assessing Water Security

Despite the limitations and fragmentation of monitoring systems, opportunities still exist for extracting useful information to guide policy on water security and climate adaptation. One example is the possibility to jointly analyze information on hydrological and ecological changes in the Arctic. The combination of these two types of information is essential for understanding hydrological controls and drivers on ecological changes, which in turn affect Arctic communities, e.g., through reindeer and caribou grazing areas, subsistence fisheries and availability of surface freshwater.

Karlsson et al. (2011) showed that reports of hydro-ecological regime shifts in the Arctic are extremely fragmented, and centered around major ecological research stations. Few reports of changes in other areas are available. However, that analysis also showed the opportunity for some of the areas, in particular where observed regime shifts coincide with good hydrological monitoring capacity, to contribute to a greater understanding of coupled hydro-ecological changes.

Other approaches deal even more directly with assessing the issue of water security in the Arctic. To handle the information challenge for remote Arctic communities, Alessa et al. (2008) proposed a measure termed the Arctic Water Resources Vulnerability Index (AWRVI). The AWRVI was developed through an iterative expert judgment process termed Delphi, in which representatives of various areas of expertise evaluated information needs and data requirements to arrive at a combined index. The AWRVI was constructed out of a perceived need to adapt other available global or regional indexes into a compound measure of both biogeophysical and socio-ecological vulnerability particularly adapted to remote communities in the Arctic.

The need for better information and monitoring in the Arctic was also noted by Evengard et al. (2011), who particularly indicated potential health risks to people in the Arctic due to lacking capacity of water infrastructure and management. A call for a set of indicators that would allow this information to be synthesized and easily accessible was put forth in Nilsson et al. (2013). That study also noted that while a systems perspective is needed for integrated understanding of threats to water security in the Arctic, establishing and using quantitative indicators of specific system components that are already feasible is a more rapid way of reaching an acceptable basic information situation.

The shortcomings in monitoring systems require that these information gaps and uncertainties be considered in policymaking. To this end, Azcárate et al. (2013) suggested an approach specific to the implementation of strategic environmental assessments in the Arctic.

There is some sign that the importance of information for informing policy in the Arctic is beginning to be appreciated more. The Sustaining Arctic Observation Networks (SAON) process, under the umbrella of the Arctic Council, aims to facilitate partnerships and synergies to make Arctic data more accessible. Although SAON is now operational, and recurring Arctic Observing Summits have been held to foster discussions and information sharing, the influence of SAON on the development of water information infrastructure in the Arctic is still uncertain.

17.4.2 Water Information and Climate Change Adaptation

In addition to the fundamental uses of water information outlined previously, water information must today also adequately consider climate change. Although the Arctic region is much in focus in climate research in general, less emphasis is put on the role of water on land, and how this will change. In fact, large-scale climate modeling has generally considered water on land of secondary importance, with greater emphasis given to accurate reproduction of major water flows between the atmosphere and the oceans. Although this emphasis is motivated for achieving principal stability and accuracy in the models representing the large-scale climate system, the question of water on land, and not just over land, is of key concern in adaptation of human society to climate change.

Until recently, developers of the large-scale models that aim to reproduce the global climate system have stressed that their output should not be considered predictions of the future. Instead, scenarios provide potential future states of the atmosphere, conditioned on certain circumstances being realized. More recently, however, interest has grown in also attempting to predict climate on time scales of high relevance to policymakers, such as decadal time frames (Trenberth 2010).

Irrespective of the intended uses of climate models, their output is bound to be used in policy-prescriptive settings, and is already being used in that way (Kundzewicz and Stakhiv 2010). The reason is simply that there is no better alternative for many parts of the world, and for many end users, as output from global climate models is provided freely online, whereas dedicated downscaling to a particular region may only be available to organizations and in regions with greater resources.

Furthermore, the downscaled modeling that provides finer-resolved and potentially more accurate climate change information for a specific region still depends on the accuracy of the reproduction of the land water system in the global-scale models. Previous studies have indicated limits to this accuracy for several model generations and regions of the world (Asokan and Destouni 2014; Bring and Destouni 2014; Jarsjö et al. 2012).

For example, Bring and Destouni (2013) showed that an environmental planner in the Arctic may have limited use of the scenarios and models that underlie the IPCC's Fourth Assessment Report in planning for where to prioritize efforts to adapt to or prepare for climate change. That study presented the degree to which recent observations of climate change, in the form of deviations from the long-term mean, aligned with climate model projections of future change. The focus of the study was to establish the degree of regional coherence, that is, the degree to which observations and models agreed on which basins that, in relative terms, were the sites of greatest impact from climate change.

The results showed that there was no agreement at all between observations and projections of where temperature change was occurring or would occur across the studied basins. For precipitation, the relation between observations and projections was even negative, so that basins with the greatest recorded positive deviation (increase) in precipitation were projected to be the basins with the smallest increases in precipitation in the future. In addition, for precipitation, the signs of the changes were also not in agreement, so that in some cases large observed decreases in precipitation were projected to turn to increases at some time in the future.

This disagreement between observations and future projections poses a challenge to planning for where resources are best spent, and several choices may be considered rational. One strategy could be to prioritize resources to the regions where observed changes are the greatest, as these are irrefutable, measured changes that have concrete impacts. Another would be to instead prepare plans based on best knowledge of future changes. A reconciliation of these two strategies is presently not possible, and in the absence of such a strategy, other information goals may need to be formulated to guide adaptation to changing water availability in the Arctic.

Another recent analysis has investigated whether models that tend to reproduce temperature observations in the Arctic are also good at reproducing precipitation observations, and vice versa (Bring and Destouni 2014). Again, for the models underlying the IPCC Fourth Assessment Report, this is not the case. This leads to difficulty in selecting a single or a few best models, something that is often done due to computational limitations, where more detailed regional climate modeling is performed using a downscaled model. A priority to best reproduce the thermodynamic system may for instance lead to selection of the best-performing model in terms of temperature simulations, which then tends to be a worse model in simulating precipitation patterns.

Furthermore, the analysis shows that models may still provide reasonable results on drainage basin scales, but for the wrong reasons. In the study, models with large absolute deviations from observed values for individual cells in some cases showed relatively small bias errors; a measure of the magnitude of averaged errors. Even though the results may appear accurate for the basin, the underlying process representation is in these cases not accurate, and should reflect a lower confidence in those models.

17.5 Conclusions

The environmental changes already taking place in the Arctic are likely to lead to dramatic changes in living conditions for its inhabitants. Along the coastlines, settlements will experience changes from multiple directions. Shore erosion, storms and rising sea levels will pressure communities from the sea, while rising temperatures, degrading permafrost and changes in surface water availability will constitute pressures on land. Further inland and south, permafrost decay and increasing economic interest in the Arctic will affect human societies.

Changes to Arctic communities in terms of water security are both positive and negative, but in all cases they present people in the Arctic with a challenge to properly manage the change. With environmental conditions moving outside the previous envelope, governance must be adaptive to change and monitor environmental parameters in order to detect and understand changes.

Water information challenges are not essentially unique to the Arctic, but the sparse population, remoteness, and increasing rate of change, as well as economic interest in the Arctic make the situation special. Although water information accessibility may improve with a successful continuation of the SAON process, there will be a continued need to use the windows of opportunity that are presented by higher information density for certain parts of the Arctic to inform understanding about wider Arctic change. A more solid prioritization basis for water monitoring networks is also needed under the dual challenges of cost efficiency and a changing background climate, as indicated by Bring and Destouni (2013).

Water security changes in the Arctic are also partly driven by other processes than those giving rise to water security issues elsewhere. Improved climate model information on the land water system will be essential to plan for adaptation to changing permafrost conditions, which in turn lead to hydrological changes, e.g., in runoff patterns and soil moisture. In this regard, further investigation and development of the land water system representation in global and regional climate models is a priority, and should complement the focus on large-scale atmosphere-ocean interactions.

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