Widespread decline in hydrological monitoring threatens Pan-Arctic Research

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Widespread Decline in Hydrological Monitoring Threatens Pan-Arctic Research

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Operational river discharge monitoring is declining in both North America and Eurasia. This problem is especially severe in the Far East of Siberia and the province of Ontario, where 73% and 67% of river gauges were closed between 1986 and 1999, respectively. These reductions will greatly affect our ability to study variations in and alterations to the pan-Arctic hydrological cycle.

Widespread loss of hydrological monitoring networks over the last 10-15 years in both developed and developing countries is of great concern to the scientific community as it seeks to manage water resources and detect the impact of global change on the hydrological cycle [Lanfear and Hirsch, 1999; Rodda, 1998; IAHS Ad Hoc Group on Global Water Data Sets, 2001]. This decline has occurred just as the global change research community has shown that the water cycle is highly sensitive to altered climate. The problem of hydrographic monitoring loss across the pan-Arctic is particularly acute and may interfere with our understanding of high-latitude and global environmental change. The information needed is critical to assessments of land-atmosphere interactions.
The monitored portion of the pan-Arctic (red outline) is shown with the density of river discharge gauges in the regional Roshydromet office (UGMS) responsibility zones in Russia, the provinces in Canada, and Alaska. Values within each administrative unit represent the number of active discharge gauges in 1986 and 1999. The red-hatched areas show the loss in monitored areas from 1986 to 1999. Original color image appears at the back of this volume.

Table 1. Status of pan-Arctic river discharge monitoring networks 1986–1999 and contemporary operational discharge monitoring (Arctic-RIMS). The monitored area (columns 3, 4), total number of gauges (columns 5, 6), and density of discharge networks (columns 7, 8) characterize the conditions of river gauge networks relative to two temporal levels 1986, 1999. Number of gauges larger than 10,000 km² (columns 9, 10) demonstrates the proportions of gauges located on large-sized rivers with regard to the total number of gauges in 1986 and 1999. Current holdings of the Arctic Rapid Integrated Monitoring System (Arctic-RIMS) are presented in columns 11, 12.

<table>
<thead>
<tr>
<th>Region</th>
<th>Total drainage area (km²)</th>
<th>Monitored Area (%)</th>
<th>Total number of gauges</th>
<th>Number of gauges per 10⁶ km² of total area</th>
<th>Number of gauges &gt;10⁶ km² (% of total number of gauges)</th>
<th>Arctic-RIMS as of May 2001</th>
</tr>
</thead>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Russia</td>
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<td>85</td>
<td>79</td>
<td>1736</td>
<td>1037</td>
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<tr>
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<td>60</td>
<td>51</td>
<td>1300</td>
<td>803</td>
<td>15</td>
</tr>
<tr>
<td>Pan-Arctic</td>
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<td>74</td>
<td>67</td>
<td>3036</td>
<td>1840</td>
<td>15</td>
</tr>
</tbody>
</table>

* North American and Russian portions of pan-Arctic.

* Includes 12 gauges from Norway.
R-ArcticNet
Whole Pan-Arctic
Russian Arctic
North America

Fig. 2. Shown here are dynamics of the river gauges in the pan-Arctic drainage basin and data available in total R-ArcticNet, the operational Arctic-RIMS project, and changes in the number of river discharge gauges in North America and Russia. In 1999, the discharge monitoring network had the same number of gauges as in 1960.

Fig. 3. The decrease in the hydrometric network is shown percentage-wise for Russian Roshydromet regional offices (UGMS), Canadian provinces, and Alaska in 1999 relative to 1986. The greatest cutbacks in discharge networks, about 70%, occurred in the more remote, northeast regions of Russia, where the discharge gauge densities were very poor even during the 1980s (see Figure 1). The networks in the remaining Russian regions were reduced from 25% to 50%. In the Canadian pan-Arctic, station closings were 38%, with decreases of 68% in Ontario, 42% in the Northwest and Nunavut Territories, and 28% in Alberta.

Gauge Decline

In terms of freshwater flow to the coastal zone, the Arctic Ocean drainage basin is the best monitored. During the 1980s, when the number of stations reached its maximum, about 74% of the total non-glacierized pan-Arctic basin area was monitored [Shiklomanov et al., 2000] (Figure 1, Table 1). Even under such favorable conditions, no measurements were taken in large regions of the basin ranging from 40% in North America to 15% in Russia. This is primarily due to the absence of stations on the Canadian and Eurasian Arctic Islands, ungauged regions near the mouths of large rivers, and the many small and medium tundra-zone catchments with rivers flowing directly to the ocean. The total area monitored decreased by 67% from 1986 through 1999 at a rate of 79% in Russia and 51% in North America because some important downstream gauges located mainly on medium- and small-sized rivers were closed (Table 1).

The closing of even one downstream site on a large river may result in significant loss of monitored area. For example, shutting down the Pilot Station on the Yukon River in Alaska reduced monitored area by 323,000 km²; fortunately, it was re-opened in the summer of 2000. A reduction in monitored area of 7% over the entire pan-Arctic basin does not appear substantial. However, to put this into perspective, it represents an area of about 1.5 million km², equal to the entire state of Alaska.

This large decrease in monitored area will lead to a significant rise in the uncertainty of estimates of the freshwater, geochemical, and sediment fluxes of the pan-Arctic drainage system. The total number of gauges is also an important index of our capacity to develop high-resolution mapping of contemporary runoff. This constitutes an essential tool for monitoring progress of climate change and for studying the overall hydrological response throughout the region. Over the last 15 years,
Continuous river discharge records longer than 30 years represent the greatest value to the scientific and water resources communities. These records are used as basic information for computing long-term hydrological characteristics [Lanfear and Hirsch, 1989]. Furthermore, they allow for the identification of long-term trends in runoff due to both natural phenomena and anthropogenic impacts. The number of gauge records longer than 30 years increased for both the Canadian and Russian pan-Arctic from 1986 to 1999 despite significant cutbacks in the total number of river discharge gauges (Figure 4a). Thus, these important sites have been well preserved. In 1986, a majority of gauges both in Canada (32%) and in Russia (37%) had records greater than 30 years. By 1999, 56% of Canadian and 75% of Russian gauges had records in excess of 30 years. Thus, river networks in both countries showed a net station loss predominantly through removal of short-duration records (Figure 4b).

Visits to regional Roshydromet offices revealed that approximately 5–8% of total currently operating river discharge gauges in the Russian pan-Arctic have not directly measured discharge for 3 to 5 years. Water discharge data for these stations are calculated using stage measurements combined only with older rating curves and other hydraulic attributes. Moreover, the frequency of discharge measurements has decreased at almost all Russian gauges. This inevitably leads to an increase in the uncertainty of discharge estimates and undermines efforts by the scientific community to make assessments of global change. In the pan-Arctic basins of Canada and Russia, more information has been lost than the 40% decline in discharge gauges would indicate.

**Sources of Network Cutbacks**

Several factors contribute to the recent loss of monitoring capacity across the pan-Arctic. The primary reason is the reduction of government funds for monitoring networks. Estimates made by Environment Canada show that the budget for hydrometeorological services, which include river discharge monitoring, decreased by about 25% from 1983 to 1997 (http://www.msc.ec.gc.ca/asd-dmps/ intl_comp_eng.htm). There are no reliable estimates of Russian hydrometeorological service budgets, but according to the director of Roshydromet [Popova, 2001], government funds in 2000 covered about 40% of the minimal demands needed to maintain the existing network.

The greatest impact on monitoring network cutbacks manifests itself as a lack of staff due to a population decline in remote regions and a "brain-drain" of qualified specialists to more economically attractive activities. In Russia, network losses were most pronounced in "brain-drain" of qualified specialists to more economically attractive activities. In Russia, network losses were most pronounced in remote, high-latitude regions (Chukotskoje and Kolymskoje UGMS), where population decreases greater than 38% have occurred since 1990. Loss of qualified personnel, due to insufficient financial support, results in poor data quality irrespective of gauge closure.

Furthermore, at the peak of the hydrological network in the early 1980s, some discharge...
gauges were used in the design of several large-scale engineering schemes, some of which were completed and some abandoned, [Shiklomanov and Markova, 1987; Day and Quinn, 1992] with a corresponding closure of sites. The majority of these gauges had no regular records and their data loss is not as severe for the global water resource community as the loss of long-term gauges.

**Strategy for Combating Gauge Network Decline**

Monitoring Arctic river discharge is crucial to a broad suite of science and engineering applications, not the least of which is the detection of climate change. Thus, the international water science community must mobilize to regain the capacity to monitor the pan-Arctic land mass. For Earth systems applications there are two strategies. One is to optimize monitoring of freshwater flow to the oceans, and the other is to lend support to atmospheric and macro-scale hydrologic studies for numerical weather prediction and climate change analysis.

The pan-Arctic drainage system is unique because most of the river discharge into the ocean is delivered through a small number of large rivers. Only 12 hydrologic gauges are sufficient to capture 91% of total monitored area and 85% of total monitored discharge (Figure 4c). There is, then, a great opportunity to organize a continuous, operational river discharge monitoring system that would provide information on freshwater discharge to the ocean. However, downstream gauges on large river basins have only a limited capacity to capture the spatial variability of surface runoff needed to support the second strategy. For describing the state of Arctic land surface hydrology it is therefore necessary to record discharge emanating from much smaller sub-basins throughout the entire pan-Arctic land mass (Figure 4d).

A prototype project to specifically address the operational monitoring of Arctic hydrological cycle is now being implemented through the Arctic Rapid Integrated Monitoring System (Arctic-RIMS). This project, a collaborative effort of the University of New Hampshire, the University of Colorado, Ohio State University, NASA’s Jet Propulsion Laboratory, and the Arctic and Antarctic Research Institute in Russia, aims to assess contemporary freshwater flux to the Arctic Ocean and to characterize spatially explicit hydrologic budgets across the pan-Arctic land mass. Initially, Arctic-RIMS is focused on land-to-ocean links. In particular, near real-time daily discharge data for 56 gauges in Alaska, Canada, Russia, and Norway are being compiled (Table 1, Figure 2). These gauges cover about 60% of the total pan-Arctic drainage, or 72% of the drainage area excluding Greenland and Hudson Bay basin.

The R-ArcticNET historical archive and operational Arctic-RIMS offer an important opportunity to monitor the progressive changes of the hydrological cycle by providing an historical benchmark against which future conditions can be compared. These archives demonstrate how a spirit of international cooperation can be used to reverse, in a small way, the otherwise troubling trend in observational hydrographic network erosion. The historical station holdings of R-ArcticNET can be found at http://www.R-ArcticNET.sr.unh.edu. Many of them are freely available without restriction.

The decline of river monitoring is occurring at a critical time in Earth’s history. We are losing the capacity to witness and understand these changes. The universal loss is both a problem and an unprecedented opportunity for international collaboration. Mechanisms need to be established now to expand and rescue valuable data resources and to cooperatively assess the changing nature of the Arctic.

**Acknowledgments**

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**BOOK REVIEW**

**Water Resources Management and the Environment**

PAGE 17

**U. ASWATHANARAYANA**


The importance of water and water resources management in today's society cannot be overstated. Simply put, water is the crux of a host of societal, political, health-related, and scientific concerns. The human population depends on the availability of clean water for activities such as direct consumption, and on water in quantity for agriculture, power production, navigation, and industrial processes, to name a few. There are numerous problems associated with the adequate amount and quality of water. The former is a problem that is global (as witnessed by water shortages in periods of drought in almost all countries of the world); the latter is a problem most severely affecting the population in developing countries. There are public health concerns associated with consumption of water of questionable quality, since water serves as a medium for the transmission of disease—malaria, for example. Among countries sharing water resources, there are political ramifications related to rights to water use. And above all, the entire debate on global change revolves around, most centrally, the role of distribution and frequency of the global water cycle.

The present book by Aswathanarayana is an incredible collection of all the issues outlined in the above paragraphs and more: social, economic, and scientific matters associated with water quality and quantity; water management—including conservation and recycling—that can be practiced by both individuals and groups. The book is definitely a compendium of 20-plus years of experience in the field of water resources management by the author. Water Resources Management and the Environment begins with a general introduction to...
Fig. 1. The monitored portion of the pan-Arctic (red outline) is shown with the density of river discharge gauges in the regional Roshydromet office (UGMS) responsibility zones in Russia, the provinces in Canada, and Alaska. Values within each administrative unit represent the number of active discharge gauges in 1986 and 1999. The red-hatched areas show the loss in monitored areas from 1986 to 1999.

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Fig. 1. The following minerals are commonly dated by the (U-Th)/He technique: apatite, zircon, and titanite.